The Submerged Induction Hardening of Gears

D.W. Ingham and G. Parrish

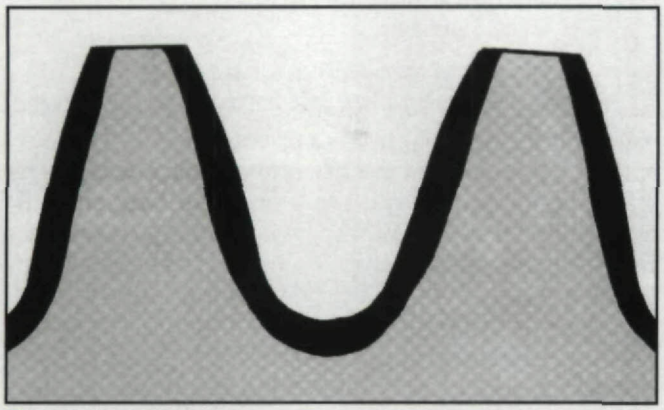

Fig. 1—Typical hardening pattern.

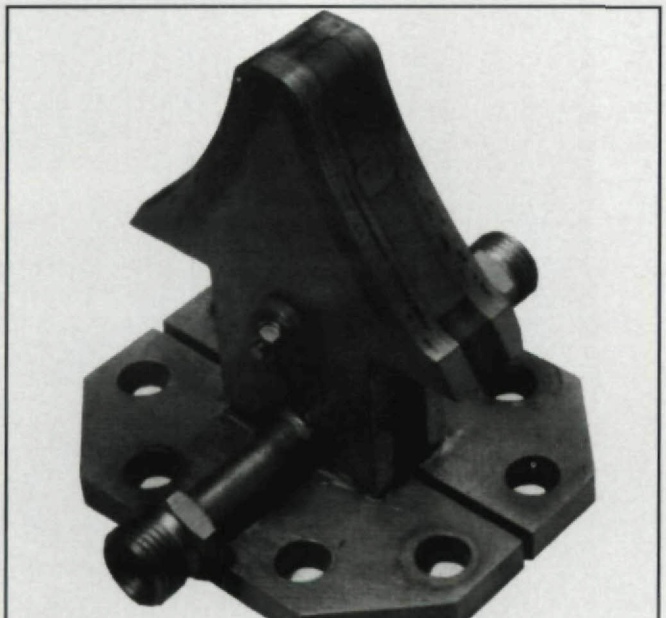

Fig. 2—The inductor.

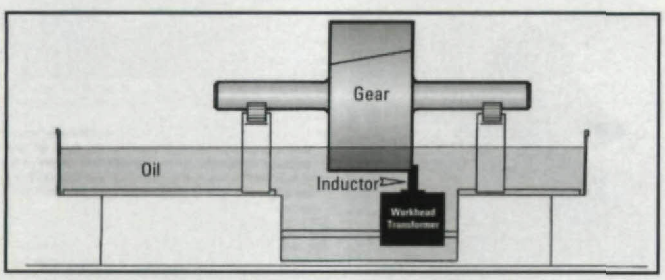

Fig. 3—Schematic diagram of the gear handling machine for tooth-by-tooth submerged induction hardening.

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Introduction

The tooth-by-tooth, submerged induction hardening process for gear tooth surface hardening has been successfully performed at David Brown for more than 30 years. That experience—backed up by in-depth research and development—has given David Brown engineers a much greater understanding of, and confidence in, the results obtainable from the process. Also, field experience and refinement of gear design and manufacturing procedures to accommodate the induction hardening process now ensure that gears so treated are of guaranteed quality. The process's purpose is to produce a continuous hardened layer, which extends along the tooth length and from the tooth's tip, down its flank, around the fillet and root area and up the opposite flank to the next tooth's tip (Fig. 1), and to ensure the depth of the hardened zone is sufficient, so the subsurface high tooth stresses are contained in the high strength regions.

In the submerged, tooth-by-tooth process, the inductor (Fig. 2), which has essentially the same shape as the space between two adjacent gear teeth, is energized and traversed along the tooth space, heating and austenitizing the neighboring tooth surfaces, including the root-fillets, as it goes. The heating operation occurs below the quenchant's surface so, as soon as the inductor has moved on, it is replaced by the surrounding quenchant; thus, heating and quenching are localized, progressive, and of short duration.

The heated and quenched zone is so localized that distortion and growth problems, which tend to plague carburize case hardening, are essentially avoided. High surface hardness and surface compressive residual stresses, imparted by the process, dramatically improve the contact and bending fatigue strengths.

This article deals with many aspects of the process itself, describes problem areas, considers applications and discusses the product's properties and quality.

The Induction Hardening Process

At David Brown, the frequency used for gear induction hardening is 9.6 kHz, and the range of tooth sizes processed is 8 to 38 module. Figure 3 is a schematic drawing of the facility, which is adjacent to a generator, water-cooling tank, oil-circulation tank and control console.

The gear handling machine rigidly supports the gear, accurately rotating, aligning and indexing it during processing. The water-cooled inductor is secured to a workhead transformer that is mounted on a carriage in the gear handling machine (Fig. 4). The workhead transformer can be set to traverse a distance of more than one meter on linear bearing tracks. The inductor's actual travel length is controlled by preset limit switches. The machine is meant for the process's submerged version, with the inductor at the bottom center position. Consequently, much of the handling equipment is in an open tank filled with quenchant during processing and drained for loading and setting up.

The generator, which provides up to 75 kW, converts the main power supply of 380 V, 50 Hz, to a medium frequency (9.6 kHz) supply at a nominal voltage of 500 V. That is transformed to a supply of 50-V energy by the 14:1 workhead transformer in the gear handling machine.

The water-cooling tank supplies three recirculatory lines:
a) to the inductor, which is capable of some heating via its own resistance and by radiation from the workpiece during processing;
b) to the quenchant's heat exchanger; and
c) to the generator and the workhead transformer.

The control console manages the induction hardening process by control of the inductor traverse speed, inductor energizing and de-energizing, quenchant flow, cooling water supplies, etc.

Over many years, David Brown performed research projects on the process, besides production hardening. Consequently, relationships between hardening parameters and hardened depth/pattern have been established, eliminating the need to establish parameters on separate test pieces.

The process is controlled by several significant parameters, these being:

1) The Inductor Workpiece Gap. The space between the inductor and the gear tooth is critical. The surface-to-volume ratio differences around the tooth profile demand different energy requirements. Consequently, the shaping of the inductor (Fig. 5) is important to optimize the coupling. The inductor is designed for rigidity to ensure accurate geometrical positioning.

Research has shown the heating effect is controlled by the inductor's design. The David Brown design includes two copper sides connected by a copper bridge along the root. Thermocouples in the body of

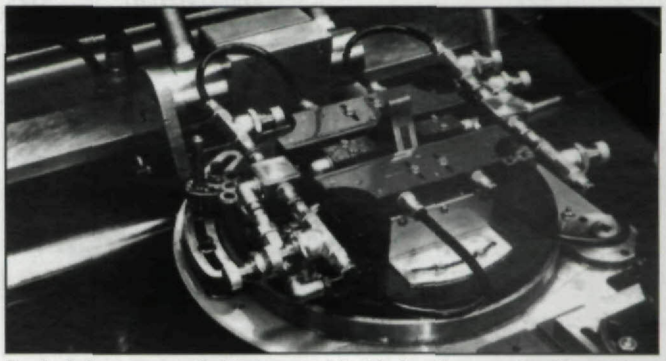


Fig. 4—Inductor surrounded by its quenching blocks, all mounted on the workhead transformer.

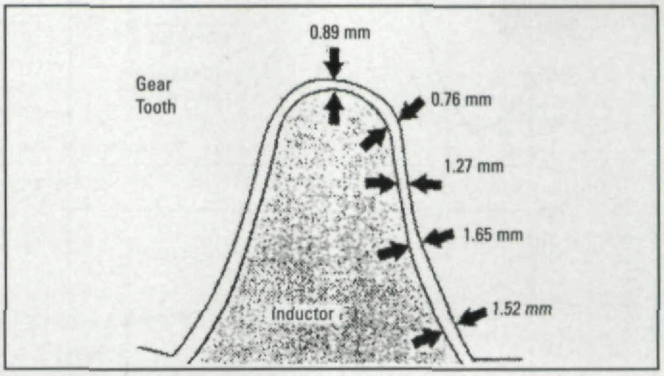


Fig. 5—Typical inductor-to-workplace coupling.

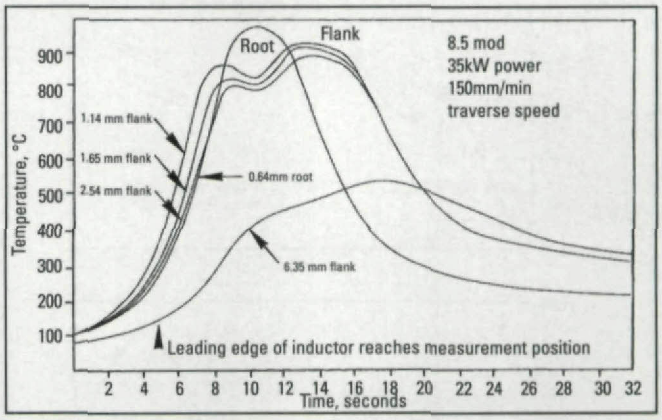


Fig. 6—An example of the temperature distribution within a gear tooth during an inductor pass. The depth and location of the temperature sensor is indicated against each temperature curve.

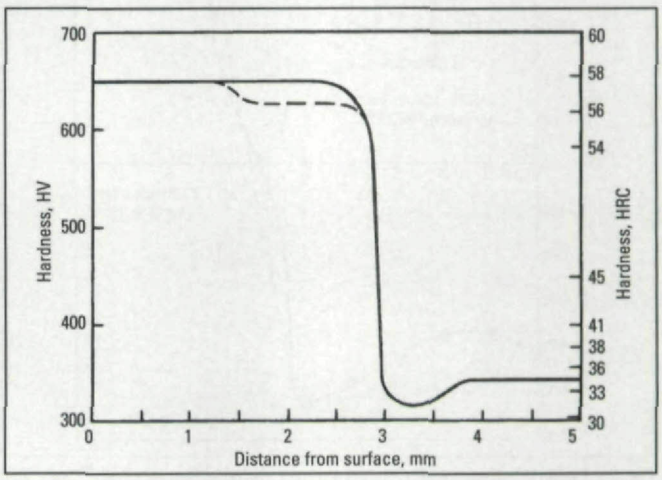


Fig. 7—Typical hardening pattern.

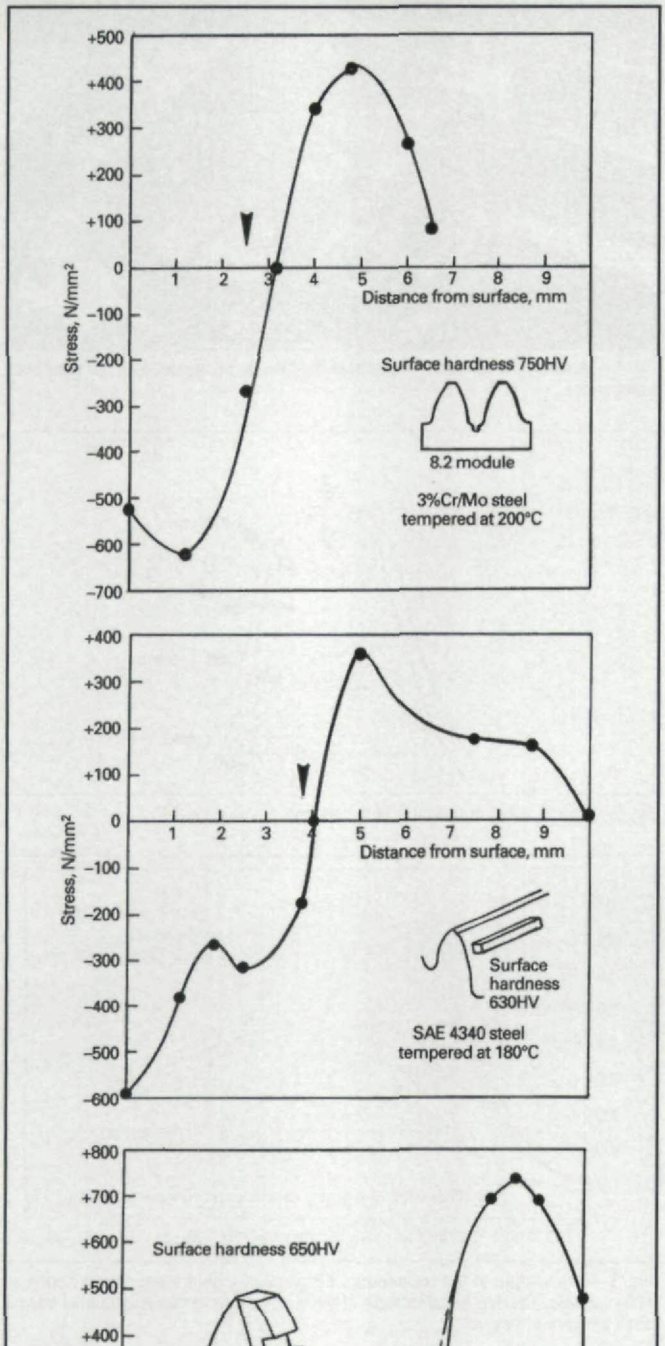


Fig. 8—Examples of residual stresses through an induction-hardened case. Test locations shown. Arrow denotes approximate effective case depth (to 450 HV).

a tooth being hardened have shown a typical temperature profile (Fig. 6). On the mid-flank position, two temperature peaks are experienced, coinciding with passage of the inductor's copper sides. In the root position, a single peak is found, associated with the copper bridge.

David Brown's practice involves the exclusive use of numerically controlled machine shaping of inductor blanks. The use of accurate shaping means it is only necessary for the operator to ensure that the inductor is aligned, central to the tooth space, and that the root gap is correct. When that is done, the inductor-to-workpiece gaps at other positions around the inductor will be correct.

2) The Power. As power is increased, the depth of heating is increased for a tooth size. It naturally follows that the larger the tooth size, the larger the power requirements.

3) Inductor Traverse Speed. Traverse speed determines the depth of heating by allowing more time for heat diffusion. Sufficient time should be available to allow transformation to austenite. Research by a dilatometry study showed that for an 817M40 (4340) steel in the quenched and tempered condition, three seconds were required to achieve carbon solution, and that a degree of coarsening with a slight reduction of hardness took place after nine seconds. Therefore, heating times within the three- to nine-second range are normal for the process, which means that if the inductor has an effective length (time above AC3) of 18 mm, the traverse speed range will need to be in the approximate range of 125 mm per minute to 350 mm per minute.

4) Quenching and cooling jets. Surrounding the mounted inductor are: a) the fore and aft quenchant curtain jets, which help stabilize the vapor phase that occupies the coupling space and hasten and control the quenching, and b) the side sprays—also curtain jets—which play on the tooth top edge and adjacent flank to control the heating pattern on the tooth's top and the amount of back-tempering on the adjacent tooth addendum. The settings for those jets, and the quantities of quenchant flowing through them, are important.

5) Power switching. When a tooth space is to be hardened, the inductor is automatically advanced into the tooth space to a distance equal to about half the inductor's length. At that point, the inductor is energized, and—after a short dwell at the entry—the inductor's traverse along the tooth space commences. Similarly, at the tooth's exit end, the inductor stops, dwells and is de-energized. That generally ensures a satisfactory hardening pattern at the tooth ends. But, experience has shown that on occasions, the exit pattern could be improved by canceling the dwell and running through on full power, or by running through and de-energizing during the exit. Those are minor adjustments aimed to ensure a good product.

Steels For Induction Hardening

At David Brown, we adopted the policy of using medium carbon alloy steels of the 4340 type composition for induction hardened applications. The

4140 type is also used in limited quantities. Those types will produce a pre-tempered surface hardness of more than 57 HRC, and a tempered surface hardness of typically 55 HRC. With today's inherently clean steels, the material's basic quality is not a problem for the hardening process.

The gear blanks are through hardened and tempered either as forgings or after rough machining. Tempering should be used to eliminate residual stresses in the gear; therefore, high tempering temperatures (>600°C) should be used. The resulting tempered martensitic microstructure is most suitable for induction hardening because it is homogeneous with respect to carbon, and the carbides' particle size is small, which favors easy solution during the short induction heating period, i.e. 3–10 seconds. The as-hardened and tempered strength need not exceed about 1,000 N/mm². Therefore, gear cutting and other machining operations are not difficult to perform.

Resulting Properties

1) Hardness. Figure 7 shows a typical hardness distribution. Induction hardened surfaces, for which the carbon content is nominally 0.40% C, usually have hardness values of more than 55 HRC, and up to 60 HRC, as hardened. Tempering at 200–250°C reduces hardness slightly to about 54–57 HRC. Two features should be noted: an added plateau of hardness (broken line), and a trough in the curve just below the case-core junction. The first feature, which is occasionally observed, may relate to the extent of carbon solution and the degree of carbon homogenization in the austenite phase, noting that for a steel such as 4340, it will take about three seconds to dissolve the carbides but more time to achieve a modest degree of homogenization. Solution and homogenization are better served by having the fine carbide characteristic induced by previous hardening and tempering. The trough at the hardened zone's end is attributed to short-term tempering. The end denotes where the temperature, due to induction heating, had attained the A1 value of say 725°C. But if the steel was previously tempered at 650°C, the core immediately beneath the case will have experienced heating within the 650–725°C range and hence some additional tempering.

2) Microstructures. An induction-hardened, low-temperature tempered material's hardened layer usually consists of fine tempered martensite, and the structure has a much refined austenitic grain-size—though that is not usually apparent. Process parameters are selected to avoid development of coarse martensitic microstructures, which can negatively influence the hardened layer's toughness.

An induction hardened layer's microstructure does not always appear martensitic, but sometimes tends to resemble the original quenched and tempered structure, though much finer. Still, induction hardening's hardness values are typical of the martensitic condition.

3) Residual Stresses. Heating of a steel surface by induction currents will be accompanied by thermal expansion and a superimposed contraction when the material

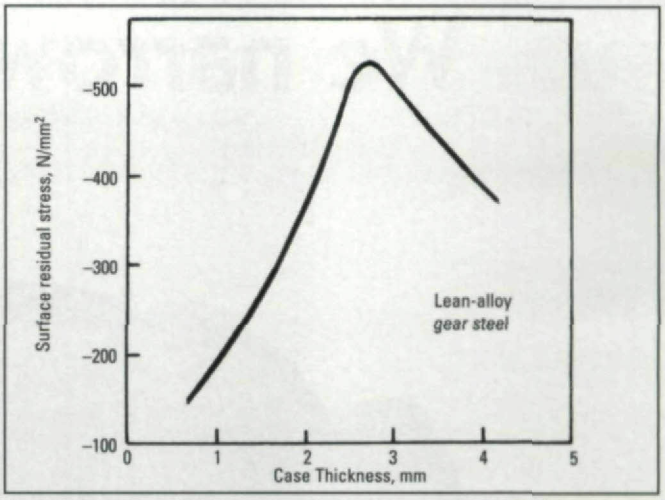


Fig. 9—Effect of case depth on surface residual compressive stress.[1]

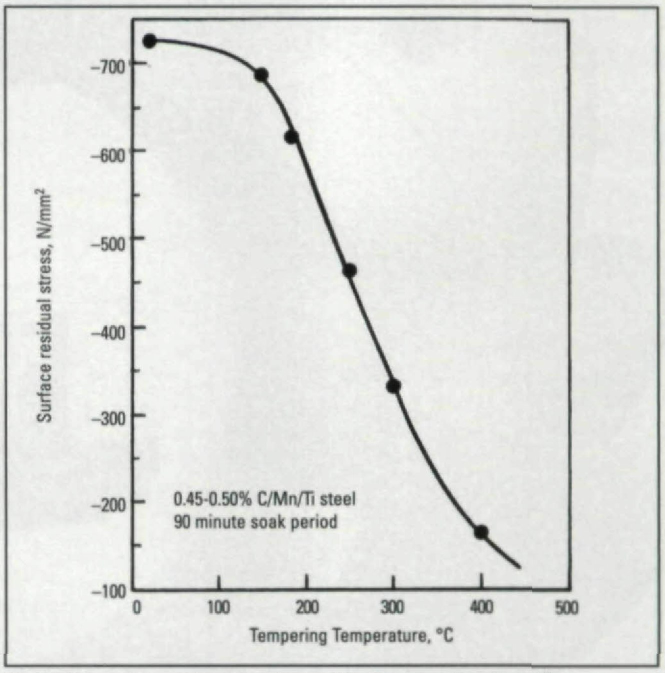


Fig. 10—Effect of tempering on surface residual compressive stress.[2]

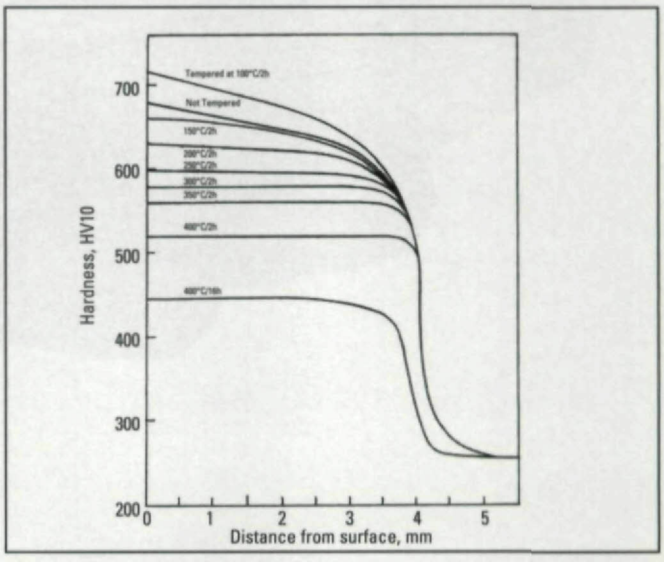
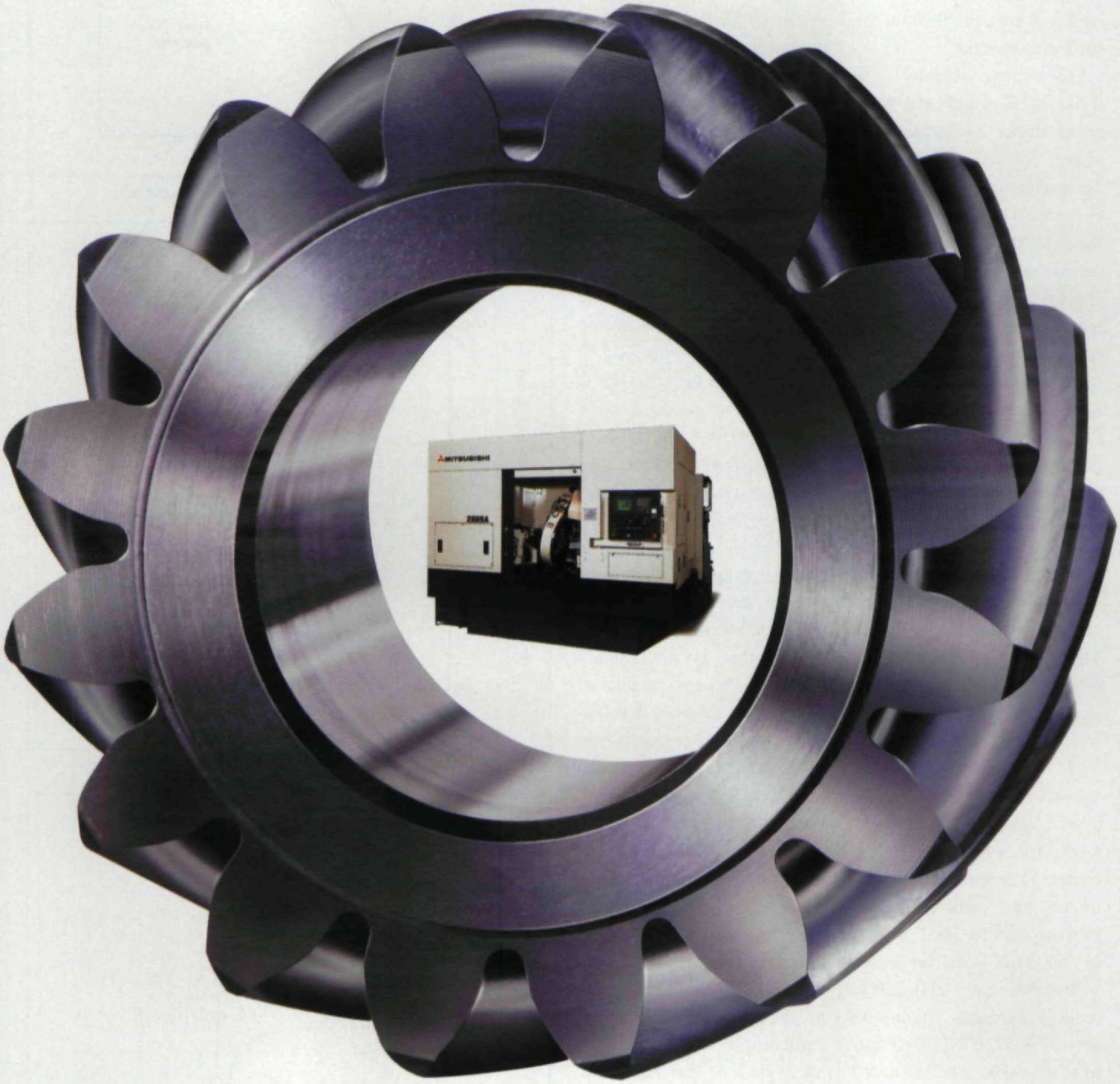
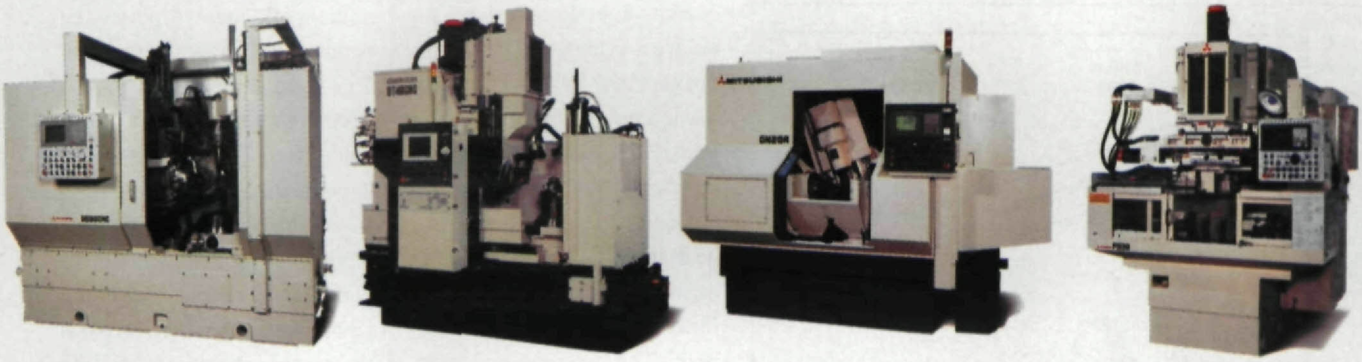


Fig. 11—Effect of tempering on the hardness profile of an induction hardened gear tooth flank (SAE 4140 steel).

We narrowed the focus.





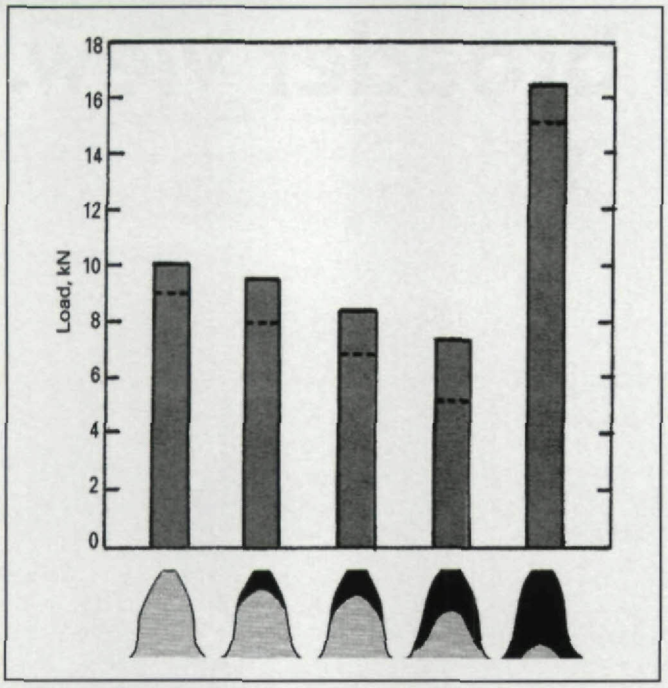


Fig. 12—Effect of the amount of flank hardening on the bending[4] fatigue strength of gear teeth. Steel 0.55% C, core strength 880 N/mm².

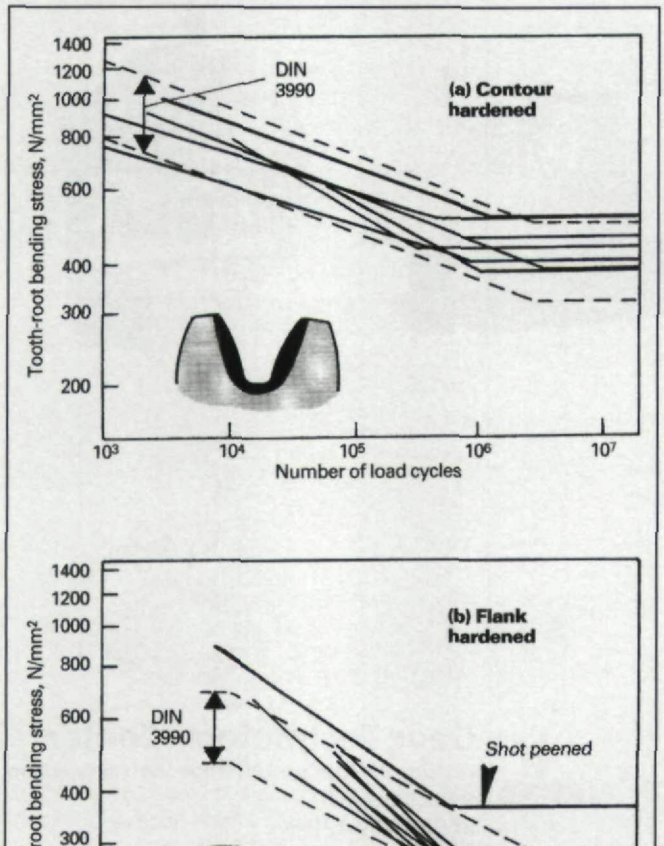


Fig. 13—The bending fatigue strength of inductor-hardened 8mm[3] module gear teeth (various steels): (a) contour hardened; (b) flank hardened. Broken lines denote scatter band for DIN 3990.

passes through the austenite transformation temperature range. As a result, yielding may occur somewhere in the heated layer, probably close to the eventual case/core junction, and will contribute to the residual stress distribution. But, the stresses' development will be mainly due to the martensitic transformation.

Martensite formation in the induction heated and quenched layer involves a volume increase above that of the underlying core material, placing the hardened surface in a state of residual compression, which is balanced by residual tension in the core, just beneath the case (Fig. 8). The change from compression to tension occurs at a depth where the hardness is about 40 HRC. But, unlike the carburizing and hardening process, which transforms the core before the carburized layer, an induction heated surface layer will lose heat during quenching to the quenchant and by conduction into the workpiece's cooler body. The outcome is a residual stress distribution where the compressive stresses in the hard case may have a high value at some distance from the surface but still within the case's harder part. Even so, the amount of surface compression is determined by the hardened layer's depth. The core tensile residual stresses, which peak just below the hardened layer, need to be carefully considered by gear designers, noting that a deeper case will push the "offending" residual tensile peak deeper, to where the applied bending stresses are of a low order. That feature results in the specification of a higher case depth than would be employed for carburized case depths.

The magnitude of the surface residual stresses developed during induction hardening is thought to be related to the depth of hardening (Fig. 9), though the stresses are modified by tempering, as Figure 10 illustrates. Tempering's effect on the hardness of an AISI 4140 induction hardened gear tooth surface is shown in Figure 11, noting that the most used tempering temperature range for induction hardened gears is 200–250°C.

4) Bending fatigue. It is crucial that the entire surface of the tooth root/fillet region is hardened. A missed area in that region, either along the fillet or at the tooth end, will lower the bending fatigue strength some 25%, compared with the tooth's strength before induction hardening (Ref. 3). Baumgartl (Ref. 4) confirmed the 25% loss (Fig. 12). With adequate root/fillet hardening, the fatigue strength will be 60% to 70% of that of a carburized gear (Ref. 3) when the surface hardness and the case depth are within reasonable limits, i.e. 590 Hv to 650 Hv, and minimum fillet case depth/module ratio is 0.25 to 0.30.

Fatigue tests employing a beam type test piece, with machined notches to simulate a 29 module gear tooth with a stress concentration factor of 1.4, produced fatigue limit values of 510 N/mm² for a 0.55% C plain carbon steel; 527 N/mm² for a 0.50% C chromium-vanadium steel; and 564 N/mm² to 630 N/mm² for steels 4140 and 4340. The trend was that the fatigue limit rose with core strength (772 N/mm² to 1,020 N/mm²), which perhaps reflected each steel's resistance to significant yielding under load. Pulsator tests (Ref. 3) on 8 mm module gears, produced the results shown in Figure 13 for full tooth space induction hardened and flank induction hardened teeth.

*5) **Contact fatigue.*** A surface's contact fatigue strength is related to its tensile strength and the surface material's hardness. Contact fatigue tests using discs and having no intentional sliding suggested that induction hardened surfaces had pitting fatigue strengths of about 80% of that of carburized and hardened surfaces (Fig. 14). Winter and Weiss confirmed that observation (Ref. 3). With actual gear tests, they concluded that induction hardened gears had 85% of the contact fatigue strengths of their case hardened counterparts. Their recommendation not to exceed 55 HRC surface hardness for the sake of tooth bending strength, is in line with current practice, noting that their contact fatigue plots, shown in Figure 15, represent surface hardnesses of 52 HRC and 61 HRC. When the surface hardness was 61 HRC, the contact fatigue strength was comparable to that of a case hardened gear of the same surface hardness. Unfortunately, with such surface hardness, some tooth bending failures occurred with the induction hardened gears. In other tests (Ref. 5) on gears of about 61 HRC, the induction hardened gear had a life (to the onset of pitting) that was 1.7 times that of a case hardened gear. Again, some induction hardened gears experienced tooth breakage, which may confirm Winter and Weiss's recommendation. But, during contact fatigue tests,

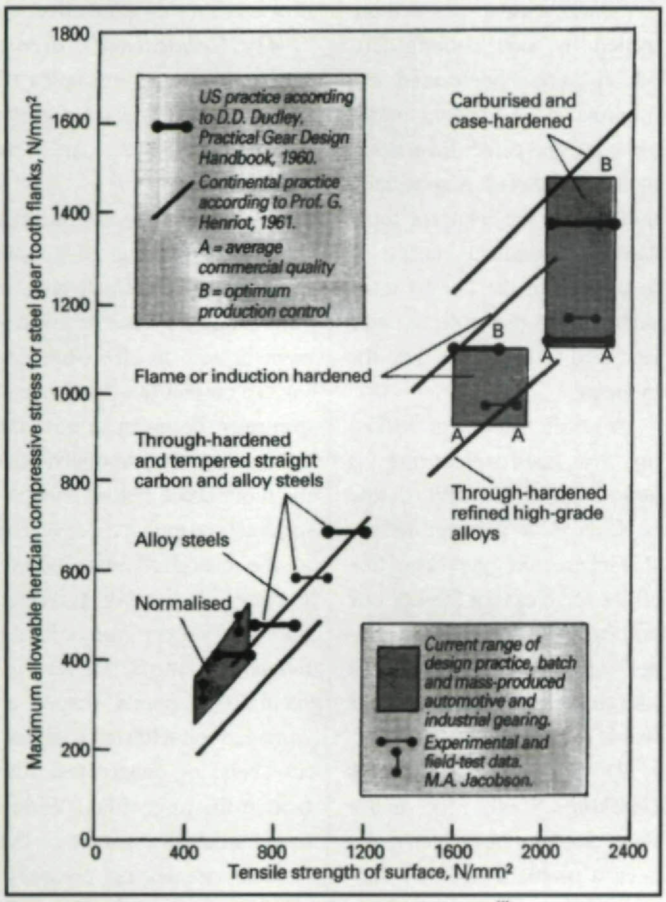


Fig. 14—The contact fatigue strength of gears. After Jacobson.[8]

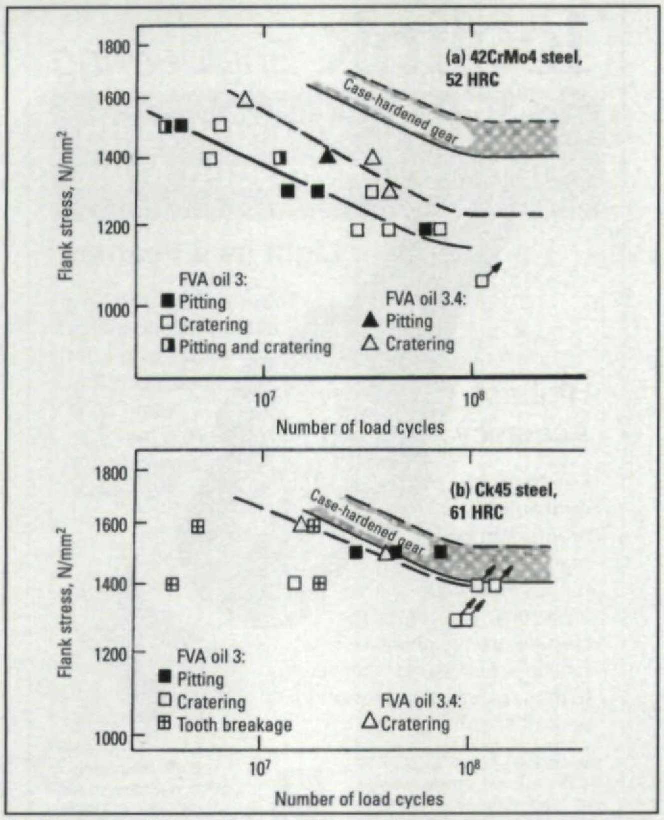


Fig. 15—Contact fatigue resistance of induction-hardened gear teeth run against **carburized teeth[3]: (a) 42CrMo4 steel/52 HRC; (b) Ck 45 steel/61 HRC. Performance of case hardened teeth shown shaded.**

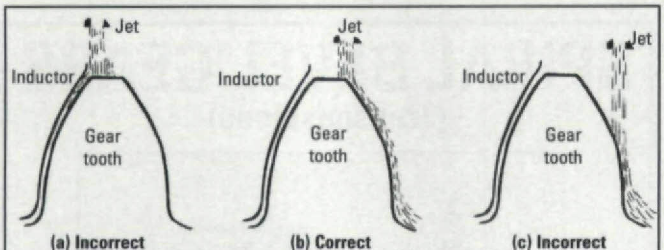


Fig. 16—Location of side jets.

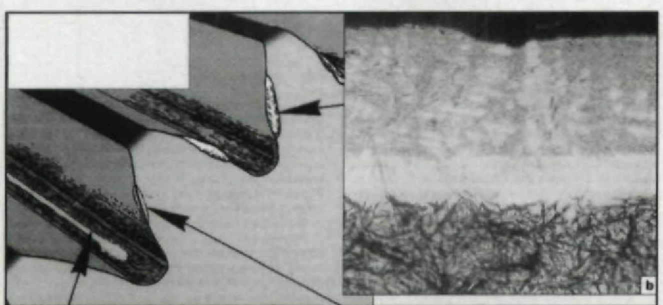


Fig. 17—Overheating and melting: (a) overheating (x450); (b) melting (x100); (c) overheating with a trace of melting (x540). Steel: 817M40.

using narrow faced gears results in tooth breakage fractures initiated at the early contact damage on the tooth flanks.

Pitfalls

Induction hardening has problems. In the wrong heat treater's hands, the results can be disastrous. But, a number of problems have been recognized and eliminated during David Brown's years of experience. That recognition provided insight and a clearer understanding of the process.

1) Back tempering. The hardening of a single tooth means the tooth surface attains a temperature in excess of 720°C. The quenchant removes much of the heat, but some heat conducts through the tooth. That heat can—particularly with small pitch teeth—result in "back-tempering" of the adjacent, previously hardened tooth.

"Back tempering" is controlled by side cooling jets, which are positioned to impinge on the adjacent tooth's top edge and direct flow down its flank (Fig. 16). A consideration is that the adjacent tooth "sees" the conducted heat a little later than the heated tooth surface, and therefore the side jets need to be longer than the inductor.

A small amount of softening by back tempering is almost inevitable and should be accepted in the gear design. It is inherent in the process that all the teeth except the last one will experience the "back-temper" effect and that one tooth (the first) will have two flanks which experience the effect.

2) Root and Flank Cracking. Tooth root and/or flank cracking has never really been a problem with the submerged, tooth-by-tooth process using quenching oil as the coolant.

The tooth-by-tooth induction hardening process in other organizations had an early history of tooth cracking problems (Ref. 1), usually via the use of steels having too high a carbon content and/or too low a hardenability together with the use of higher quench rates.

3) Melting and Overheating. If the local temperature becomes too high due to, for example, too close a couple, there will be a risk of surface overheating or melting. Overheating produces a coarse martensitic microstructure in the as-quenched surface. A melted area produces a surface layer with a dendritic structure and a sublayer of overheated material (Fig. 17). Such occurrences are to be avoided, although localized occurrences at tooth end run outs can be dressed to remove the effects.

4) Unhardened areas. Figure 18 shows examples of induction hardened gears where small areas are left unhardened.

In (a), an inductor did not dwell at either end of a gear tooth, causing a small area, a "thumbnail," to receive insufficient heating to effect hardening. To correct that fault, attention must be given to how far the inductor is introduced into the tooth space before energizing and how long it dwells there in the energized state before starting its heating traverse. Such a defect may invite fatigue cracking during service.

In (b), a poorly shaped or damaged inductor led to a narrow band of unhardened surface at the tooth fillet. Within the hardened surfaces, the residual stresses are compressive. But in unhardened areas, such as those shown, there will be tensile residual stresses of a high magnitude (Fig. 19). A gear tooth with such a defect will have a very poor bending fatigue strength.

In (c), insufficient attention to process parameters led to the hardened layer being thin, or missing, near the tooth's end. It is normal for the end hardened pattern to differ a little from that further along the tooth; there tends to be a small amount of case thinning near the exit end at a point midway up the tooth face, as the top row in Figure 18 shows. In extreme circumstances, the thinner area may break out to the surface.

One very important factor in relation to tooth end hardening problems is having the correct tooth end shape, chamfers and beveled edges.

5) Uneven hardening patterns. Uneven hardening patterns are mainly due to poor positioning of the inductor in the tooth space or to a lack of inductor rigidity. Poor inductor alignment also causes uneven hardening.

6) Distortion and growth. Shape and volume changes are not, as a rule, viewed as being significant to induction hardening. Still, it is good to keep in mind that they do occur, though generally to small degrees, and good to know where the potential problem areas might be. Tooth profile movements due to induction hardening are illustrated in Figure 20, where the shape change is less than 0.012 mm.

Gear rims might also have a slight tendency to take on a diabola shape, when the gear diameter at the ends of the teeth is greater than the mid-face width. The extent of the shape change is affected by rim thickness and tooth face width; the thinner the rim and the greater the face width, the greater the risk of that form of distortion. Therefore, the designer must take that into account at an early stage of design. Given that tendency, it is not advisable to induction harden gear rims "shrunk" onto a center. Welded fabrication gear construction, on the other hand, is suitable.

The ends of small- and intermediate-sized teeth, which are required to be induction hardened, should be generously radiused. On the other hand, large pinion teeth, for which a deep case is specified and which are not planned to be flank ground, should be tapered about 0.1 mm over the end 1/20th of flank, at both ends of each flank, as well as having a 3 mm radius at the edges. That is done to counter

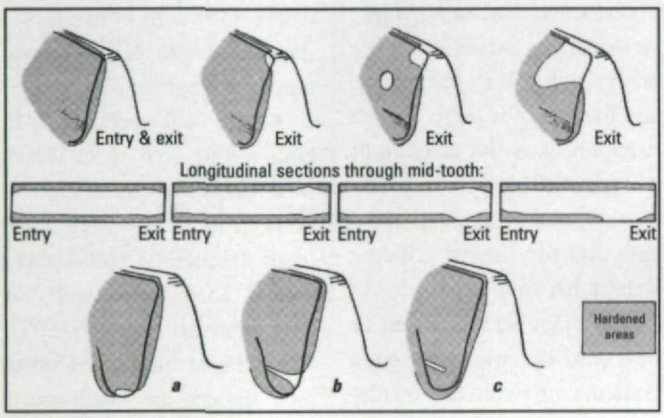


Fig. 18—Mis-hardened zones

Table 1—AGMA gear ratings for various heat-treated conditions.

Gear tooth size		AGMA rating (kW)				
Module	DP	Through hardened to UTS of 772N/mm²	Through hardened to UTS of 1158N/mm²	Nitrided 4140	Induction hardened	Carbon case-hardened
2	12.7	1.5	2.9	3.3	3.6	4.2
2.5	10	3	5.6	6.6	7.2	8.3
3	8.5	5	9.4	11.1	12.1	14
4	6.35	11.6	21.8	26	28.3	32.9
6	4.23	38.7	72.9	84.5	94.9	111
8	3.18	88.6	167	194	218	256
12	2.12	282	530	615	691	815
20	1.27	1163	2192	2558	2875	3390
30	0.85	3521	6636	7723	8680	10258

Results based on 25 pinion teeth running against 75 wheel teeth; helical with face width 0.4 x centres.

Table 2—Appropriate heat treatment related to gear tooth size.

Gear tooth size		AGMA rating (kW)			
Module	DP	Nitrided	Induction hardened at 50kHz	Induction hardened at 10kHz	Carbon case-hardened
2	12.7	●			●
2.5	10	●			●
3	8.5	●	●		●
4	6.35	●	●		●
6	4.23	●	●	●	●
8	3.18	●	●	●	●
12	2.12			●	●
20	1.27			●	●
30	0.85			●	●

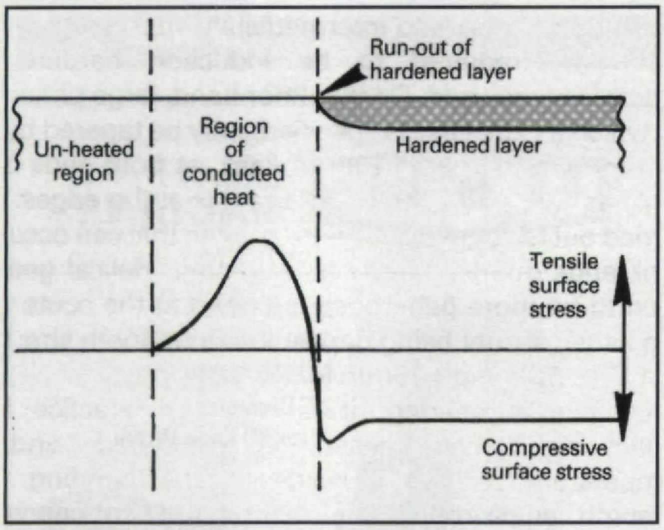


Fig. 19—Residual stress at the edge of a hardened layer.[4]

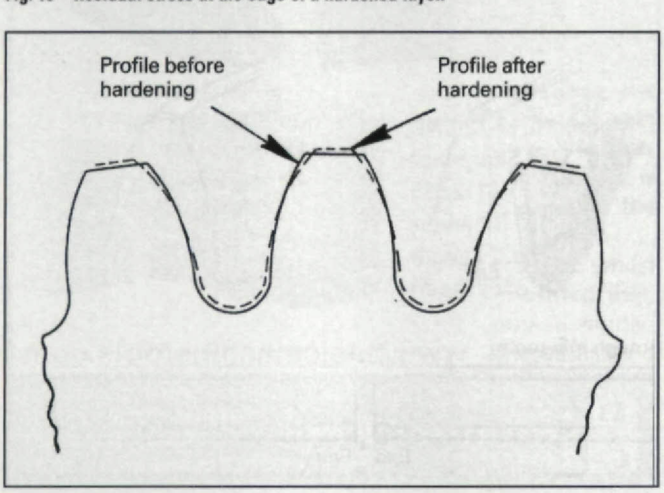


Fig. 20—Distortion in tooth form caused by hardening (greatly exaggerated).

the minor growth that can occur at the flank ends due to induction hardening, thereby causing hard meshing points in critical areas. Helical gear teeth need to be more generously rounded at the acute angle's edge, the amount depending on tooth size.

Applications

Induction hardening joins an array of heat treatment processes available to the designer. A process comparison of the AGMA 218 gear ratings for a range of gear tooth sizes is shown in Table 1. It can be seen that carburized and case hardened gears provide the best ratings for both tooth durability (contact fatigue) and tooth bending fatigue gear properties. But, for the larger tooth sizes, induction hardening provides a significant advantage over nitriding or through hardening.

The different heat treatment processes tend to suit a range of tooth sizes. Table 2 provides an overview of the data. Tooth-by-tooth induction hardening is suited to relatively large teeth—or 10 kHz frequency from 8 module to 30 module.

Induction hardening, because it requires a high level of technical and manual skill, is suited to larger gears, which—by their size and weight—are expensive to carburize.

Induction hardening might be beneficial when distortion and growth due to carburizing and hardening is large enough to require excessive amounts of corrective flank grinding, with a corresponding thinning of the case and the risk of grinding steps at the tooth fillet.

Induction hardening can be best used by ensuring a good combination with the mating gear, i.e. an induction hardened wheel with a carburized and hardened pinion, or a through hardened wheel with an induction hardened pinion.

After an induction hardening process is chosen, the engineer should design the gear accordingly.

1) Double helical gears should have a gap between the two helixes into which the inductor can pass when it has completed a tooth traverse. Modern hobbed gears will have that anyway, and gears that need to be finished by gear tooth flank grinding will have a substantial gap.

2) If there is a shoulder adjacent to the end of the gear portion, there should be a radial gap between the ends of the teeth and the shoulder.

3) A generous root fillet radius should be included and narrow tip widths should be avoided.

Typical David Brown applications for induction hardened gears are:

- Mill pinions on girth gear driven rotating mills where the pinion mates with a cast steel wheel (Fig. 21).
- Heavy-duty crane travel drive gearing where the needed contact accuracy by heavily loaded carburized gearing cannot be achieved in a continuously flexing gear case (Fig. 22).
- Sugar mill drive gears where price competitiveness is combined with heavy torque transmission (Fig. 23).
- Steel mill applications in both rolling mill main drives (Fig. 24), and in shear applications (Fig. 25) where each tooth frequently feels heavy shock loads, as well as coiler/uncoiler boxes.
- Cement mill drives where high torques are continuously applied for long periods (Fig. 26).

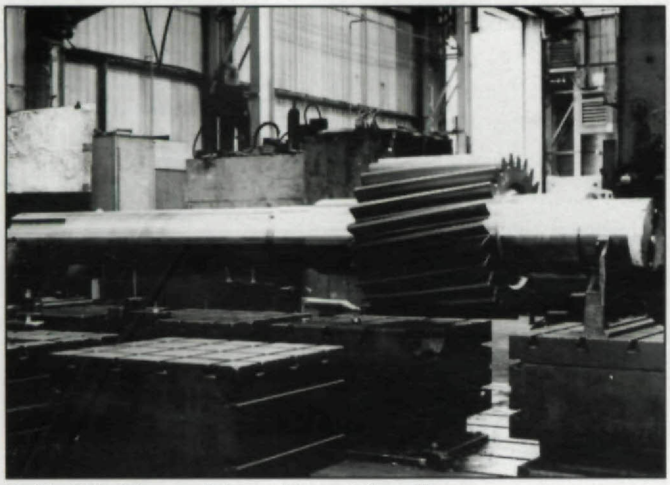


Fig. 21—Mill pinions on girth gear driven rotating mills.

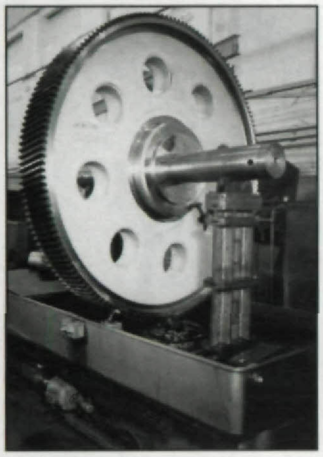


Fig. 22—Heavy-duty crane travel drive gearing.

Applications for induction hardened gears include a variety of applications where the economic balance requires a high strength, through hardened wheel and consequently an even higher duty pinion, or when the ratings demand a carburized pinion, but not a carburized wheel.

The whole range of industrial gear drives can benefit from properties produced by the process.

Conclusions

The submerged, tooth-by-tooth induction surface hardening process for medium and large gear manufacture has been used successfully by David Brown for more than three decades. It comes into its own for gears that cannot be surface hardened by other methods because of the gears' overall size or because of tooth size considerations. Also, it can compete with other processes for which strength requirements are too severe for through hardened gears but fall short of the strengths from carburizing and hardening.

For gears hardened by the process, the surface strength properties (bending and contact fatigue) are much higher (typically 40%) than the highest practicable through hardened gear but marginally less than carburized, case hardened gears (typically another 20% higher). Also, through hardened gears at the high strength levels must use low tempering temperatures, which can result in retention of internal stresses residual from the quenching process. The internal tensile stress can, combined with applied service loads, be detrimental to gear life.

Consequently, with suitable gear design modifications, the submerged induction hardening process serves as an alternative to either through hardening or carburizing.

Contact fatigue strength relates to surface hardness. Therefore, given adequate case thickness, one might expect an induction hardened gear to be

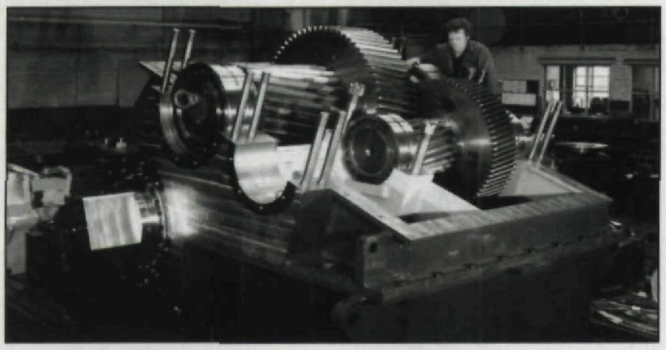


Fig. 23—Sugar mill drives.

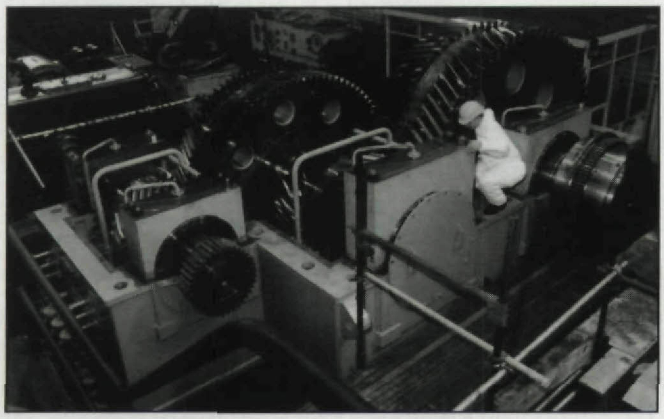


Fig. 24—Steel mill applications.

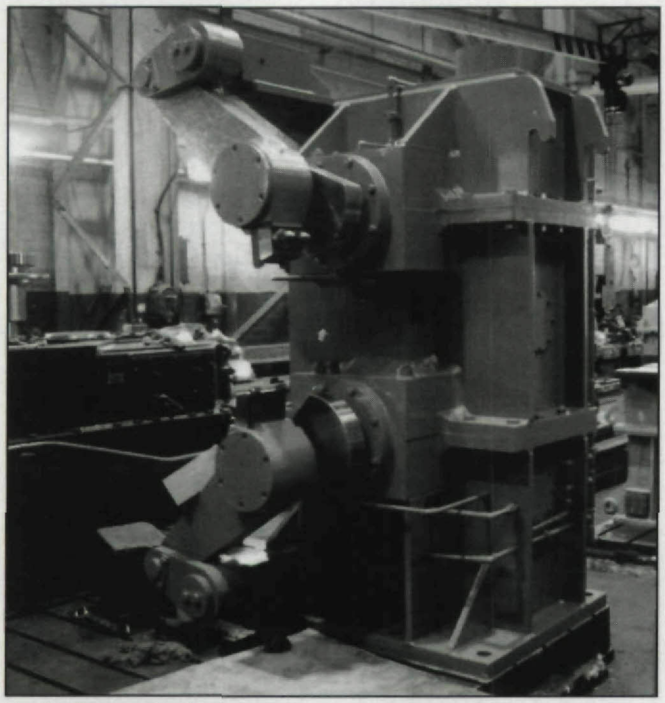


Fig. 25—Shear applications.

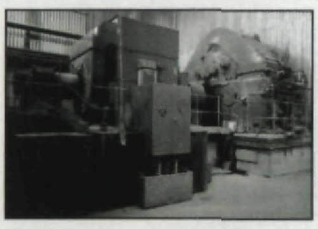


Fig. 26a

Fig. 26b

fairly comparable to a carburized gear of the same design and surface hardness. Gear testing seems to support that, and it is common for a carburized pinion to be run with an induction hardened wheel.

Induction hardening had problems in the past; in many induction hardening plants, the problems still abound. But, learning from experience and understanding the process, quality control techniques can be established that minimize the likelihood of process related service problems.

The process is gear tooth friendly. Finally, a more detailed technical appraisal of the process was published in Refs. 6 and 7.

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Geoffrey Parrish

is a gear consultant with 42 years of work experience in metallurgy, 27 of them in gear metallurgy. He was head of metallurgical research and development at David Brown Gear Industries Ltd., where he worked for 15 years, specializing in gear heat treatment processes and material properties. Also, he was chief metallurgist and deputy quality manager at British Jeffrey Diamond Dresser UK, where he worked for 12 years, specializing in gear heat treatment processing and quality.

David W. Ingham

is a manager at David Brown Special Products Ltd. with responsibility for providing gears, gearboxes and service in the United Kingdom and South America. A metallurgist, he joined David Brown in 1970, starting in metallurgical research and development. In the 1970s and 1980s, he worked on projects that included developments in submerged induction hardening. He is a member of the Institute of Materials and a chartered engineer.

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