

The Submerged Induction Hardening of Gears

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

With examples of field failures directly attributable to Tooth by Tooth Induction Hardening, there has been a negative feeling against the use of this process. This paper shows successes of this process founded on Process Development and Quality Control. A case for and against Tooth by Tooth Induction Hardening is laid out for the reader to draw their own conclusion.

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The Submerged Induction Hardening of Gears

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Synopsis

Viewing the Gearing Industry from our base in the UK we feel the *Passion* built up against the *Tooth by Tooth Induction Hardening Process* for Gears. This *Passion* is particularly strong in the USA.

We would like to strike a blow against this *Passion* and this paper is intended for this purpose.

In staking our Claim for the Process we do understand the anti-feelings - which are based on numerous examples of field failures directly attributable to the Process. Our Claim is founded on Process Development and Quality Control, features which are absolutely essential to the integrity of Gears manufactured using the *Tooth by Tooth Induction Hardening Process*.

We would seek to encourage Engineers to embrace this impressive tool and thereby achieve notable Gear Rating Enhancements. By attainment of an in-depth understanding of the Process, together with rigorous Quality Control these Enhancements are worthy of the effort.

This paper lays out the case for and against Tooth by Tooth Induction Hardening for the impartial, and partial observers to draw their own conclusions.

INTRODUCTION

The tooth by tooth, submerged Induction Hardening Process for gear tooth surface hardening has been successfully carried out at David Brown, for well over thirty years. During that time Process 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 the refinement in gear design and manufacturing procedures specifically to accommodate the Induction Hardening Process now ensures that gears so treated are of guaranteed quality. The purpose of the process is to produce a continuous

hardened layer which extends along the entire length of the tooth, and from the tip of one tooth, down the flank, around the fillet and root area and up the opposite flank to the tip of the next tooth (Fig 1) and to ensure that the depth of the hardened zone is sufficient so that in service the subsurface high tooth stresses are contained within 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 energised and traversed along the tooth space heating and austenitising the neighbouring tooth surfaces, including the root-filletts, as it goes. The heating operation, which is of a short duration, takes place beneath the surface of the quenchant so that as soon as the inductor has moved on it is replaced by the surrounding quenchant; thus, heating and quenching are very localised, progressive, and of short duration.

The zone being heated and quenched during this process is so localised that the *distortion and growth problems*, which tend to plague carburize case hardening, are essentially avoided. By virtue of a high surface hardness and the presence of the surface compressive residual stresses, imparted by the process, the contact and bending fatigue strengths are dramatically improved.

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

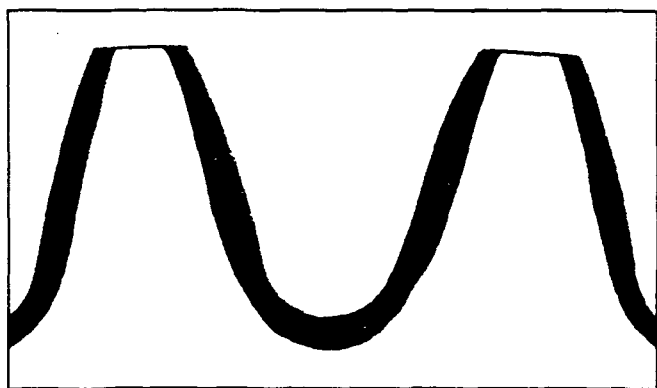


Fig 1. Typical Hardening Pattern

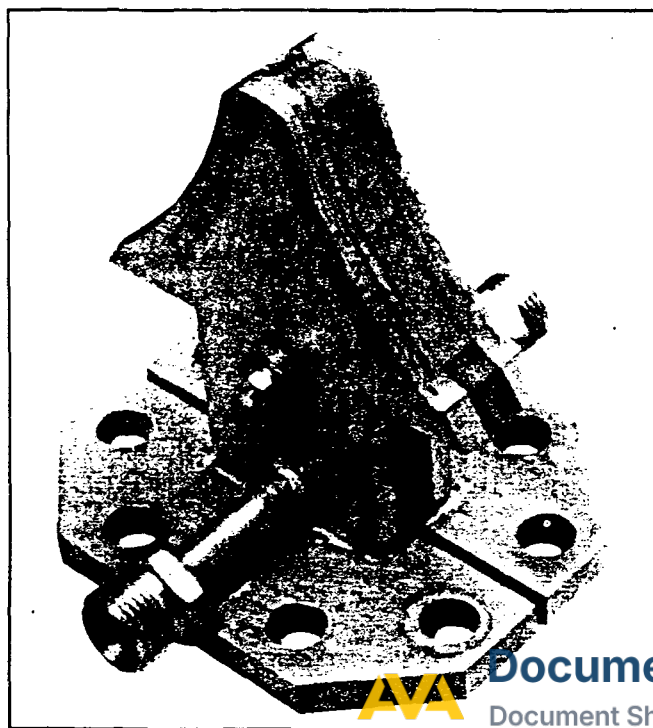
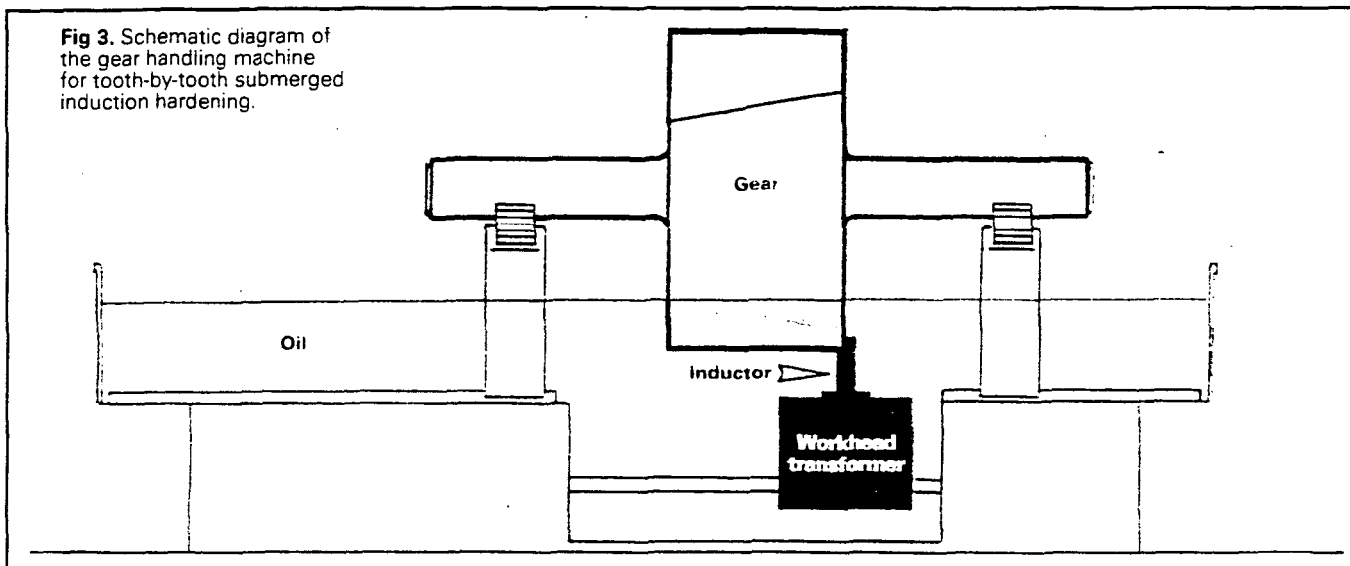


Fig 2. The Inductor

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



THE INDUCTION HARDENING PROCESS

At David Brown the frequency used for Gear Induction Hardening is 9.6kHz, and the range of tooth sizes processed is 8 to 38 module. The Facility is shown schematically in Fig 3. Adjacent to this is a generator, water cooling tank, oil circulation tank and control console.

The Gear Handling Machine rigidly supports the gear, accurately rotates, aligns and indexes it during processing. On this plant the water-cooled inductor is secured to a workhead transformer which itself is mounted onto a carriage within the gear handling machine (Fig 4). The workhead transformer can be set to traverse a distance of over 1 metre on linear bearing tracks. The actual length of inductor travel is controlled by pre-set limit switches. Because the plant is intended for the submerged version of the process with the inductor at the bottom centre

position, much of the handling equipment is contained in an open tank which is filled with quenchant during processing, and drained for loading and setting up.

The generator which provides up to 75 Kw of energy for the process, converts the mains power supply of 380volts, 50Hz., to a medium frequency (9.6kHz.) supply at a nominal voltage of 500v. This is transformed to a supply of 50v, 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.
- c) To the generator and the workhead transformer.

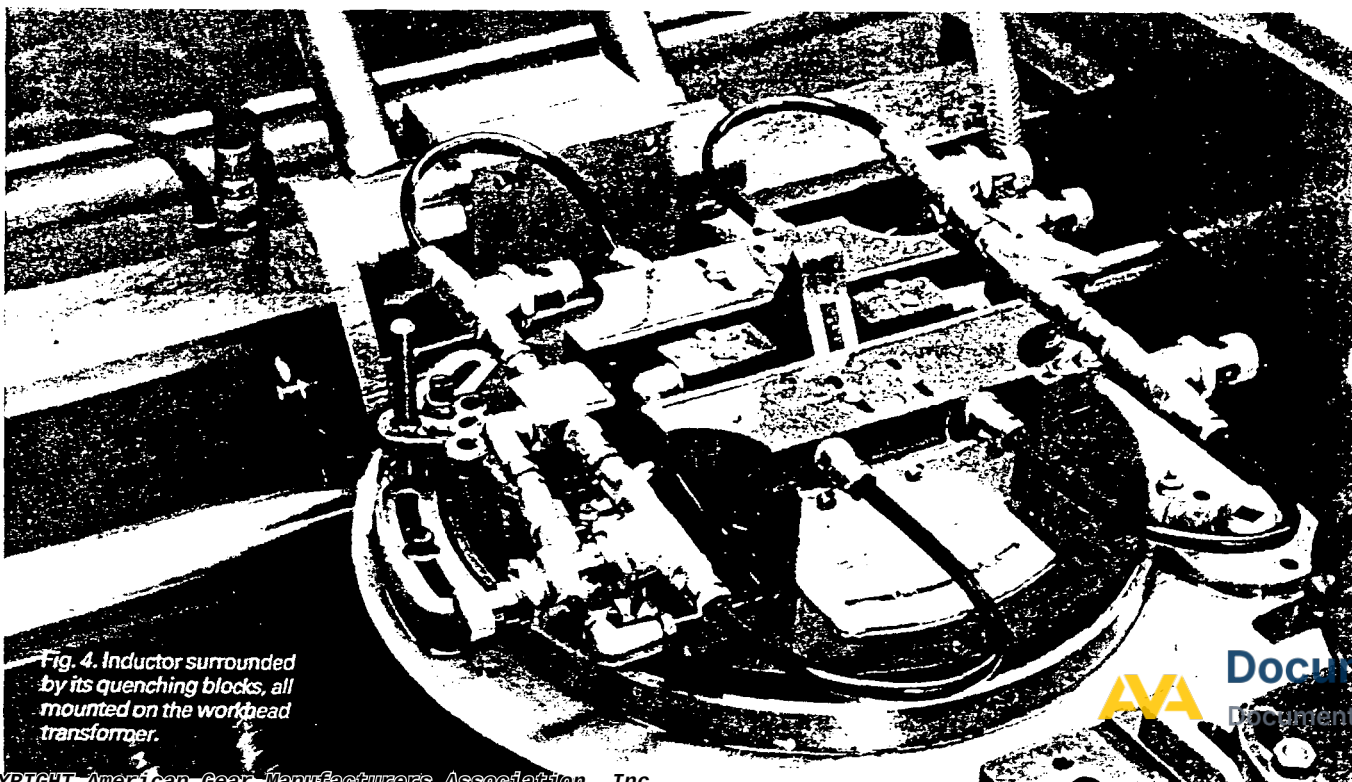


Fig. 4. Inductor surrounded by its quenching blocks, all mounted on the workhead transformer.

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

Over many years David Brown have performed Research Projects on the Process in addition to Production Hardening. Consequently relationships between hardening parameters and hardened depth/pattern have been established. As a result the need to establish parameters on separate test pieces has been eliminated.

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

1) The Inductor Workpiece Gap

This is the space between the inductor and the gear tooth and is quite critical. The surface to volume ratio differences at locations around the tooth profile, demand different energy requirements. Consequently the shaping of the inductor (Fig 5) is important to optimise the coupling. The inductor is designed for rigidity to ensure accurate geometrical positioning.

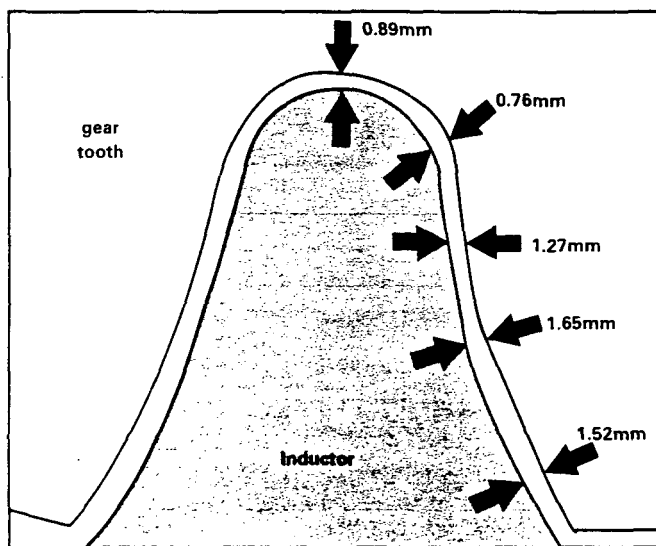


Fig 5. Typical inductor-to-workpiece coupling

Research has shown that the heating effect is controlled by the design of the Inductor. The David Brown design incorporates two copper sides connected by a copper bridge along the root. Strategically placed thermocouples within the body of a tooth being hardened have shown a typical temperature profile Fig 6. On the mid flank position two temperature peaks are experienced, coinciding with the passage of the copper sides of the inductor. In the root position a single peak is found, associated with the copper bridge.

The practice at David Brown involves the exclusive use of Numerically Controlled Machine Shaping of Inductor Blanks. The use of accurate shaping means that 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 this is done, the inductor to work-piece gaps at other positions around the inductor will be correct.

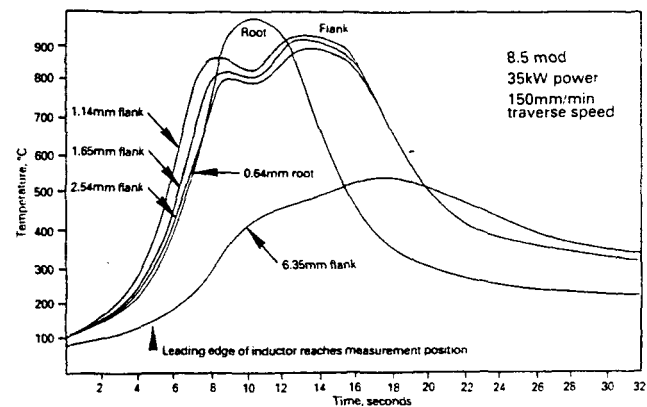


Fig 6. An example of the temperature distribution within a gear tooth during an inductor pass. The depth and location of the temperature sensor is indicated against each temperature curve.

2) The Power

As the Power is increased so the depth of heating is increased for a given tooth size. It naturally follows that the larger the tooth size the larger will be the Power requirements.

3) Inductor Traverse Speed

Traverse Speed also determines the depth of heating by allowing more time for heat diffusion. Sufficient time should be available to allow transformation to Austenite and 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 durations 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 18mm, the traverse speed range will need to be in the approx range of 125 - 350mm/min.

4) Quenching and cooling jets

Surrounding the mounted inductor are: a) the fore and aft quenchant curtain jets which help to stabilise the vapour phase which occupies the coupling space, and also hasten and control the quenching. b) the side sprays, also curtain jets, which play on the tooth top edge and adjacent flank so as to control the heating pattern on the top of the tooth, and the amount of back-tempering on the adjacent tooth addendum. The settings for these jets, and the quantities of quenchant flowing through them is 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 energised, and after a short dwell at the entry the traverse of the inductor along the tooth space commences. Similarly at the exit end of the tooth, the inductor stops, dwells, and is then de-energised. This generally ensures a satisfactory hardening pattern at the tooth ends. However, experience has shown that on occasions the exit pattern could be improved by cancelling the dwell, and running through on full power, or by running through and de-energising during the exit. These, of course, are minor adjustments aimed to ensure a good product.