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Low Distortion Heat Treatment of Transmission Components

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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

In many applications the high demands regarding service life of transmission components can be reached only by the application of a customized case hardening. This case hardening process results in a wear resistant surface-layer in combination with a tough core of the component.

However as a side-effect the components get distorted during heat treatment. This distortion has a significant cost-impact, because distorted components often need to be hard-machined after heat treatment. Therefore the proper control of distortion is an important measure to minimize production costs.

By applying the technology of low pressure carburizing (LPC) and high pressure gas quenching (HPGQ) heat treat distortion can be significantly reduced.

HPGQ provides a very uniform heat transfer coefficient. The predictability of movement during quenching is more certain and uniform throughout the load. Further improvements can be achieved by "Dynamic Quenching" processes where the quenching severity is varied during the quench sequence by step control of the gas velocity. Proper fixturing is another factor for distortion control. Modern CFC-materials (carbon reinforced carbon) are well suited as fixture-material for gas quenching.

The paper presents how LPC and HPGQ processes are successfully applied on Internal ring gears for a 6 speed automatic transmission. The specific challenge in the heat treat process was to reduce distortion in such a way that subsequent machining operations are entirely eliminated. As a result of extensive development in the quenching process and the use of specialized CFC- fixtures it was possible to meet the design metrological requirements.

The Internal ring gears addressed in this report have been in continuous production since 2006. Subsequent testing and monitoring over a two year period progressively demonstrated that consistent metrology was achieved and quality inspection was reduced accordingly.

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Introduction

Proper distortion control has become even more important than in previous days. To answer the demand for fuel-efficient vehicles, modern transmissions are built much lighter. Therefore the components of the transmission exhibit less wall-thickness which makes them more sensitive to distortion. Distorted gear components cause noise in the transmission, can require post heat treat machining processes and may even create problems during transmission-assembly. Therefore distortion control has become more important than ever.

By applying the technology of Low Pressure Carburizing (LPC) and High Pressure Gas Quenching (HPGQ) heat treat distortion can be significantly reduced. LPC is a case hardening process which is performed in a pressure of only a few millibar using acetylene as the carbon source in most cases. During HPGQ the load is quenched using an inert gas-stream instead of a liquid quenching media. Usually nitrogen or helium are used as quench gas.

With an optimized distortion control it is possible to simplify the process chain significantly. Figure 1 shows how the process chain can be simplified, if the specified geometrical values of the components can be guaranteed after gas quenching.

If the simplified process chain can be applied, then this will result in lower costs per part, lower through-

put times and lower energy consumption during production. Since there is no need to dispose any oil after the quench and since cleaning operations after the quench are unneeded, the simplified process chain is much more environmentally friendly as well.

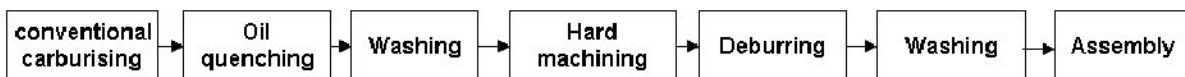
For the Internal ring gears addressed in this report, the parts used to be heat treated with an induction hardening-process. This process requires a 50 carbon and high alloy steel-grade, which is very challenging for machining, or a non-ferritic grade of cast iron, which is challenging for casting. So the intent was to change from induction hardening to case hardening and to guarantee a low level of distortion after case hardening, to allow for direct assembly into transmission.

Distortion mechanisms

The plastic deformation of metallic components during heat treatment is referred to as distortion. Distortion occurs if the stress in the material exceeds the yield stress of the material. During case hardening the components are exposed to high temperatures in the range of 880°C to 1050°C and the yield stress decreases strongly with increasing temperature of a component. Three different types of stress in the material need to be distinguished:

- Residual stresses (they are induced before heat treatment by casting, forging, machining etc.). [1]

Conventional process chain



New process chain

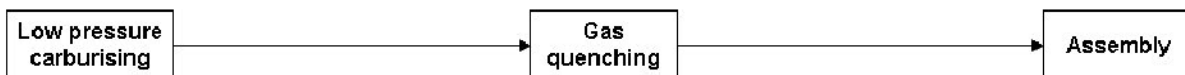


Figure 1. Conventional and new process chain for the manufacturing of gear components

- Thermal stresses (they are caused by the temperature gradient while heating and quenching).
- Transformation stresses (they are caused by the transformation from ferrite to austenite during heating and transformation from austenite to martensite/bainite during quenching).

These three types of stresses overlay with each other and add up to the total stress in the component. They are influenced by part-geometry, steel-grade, casting, forging, machining etc., and they depend on the heat treatment. If the total stress in the component exceeds the yield stress, then plastic deformation (distortion) of the component takes place. The chronology and the height of the three types of stresses leading to distortion are dependent on numerous different factors, see Figure 2.

High pressure gas quenching (HPGQ)

The technology of high pressure gas quenching (HPGQ) offers a tremendous potential to reduce heat treat distortions. Conventional quenching-technologies such as oil- or polymer-quenching

exhibit very inhomogeneous cooling conditions. Three different mechanisms occur during conventional liquid quenching: film-boiling, bubble-boiling and convection. Resulting from these three mechanisms the distribution of the local heat transfer coefficients on the surface of the component are very inhomogeneous. These inhomogeneous cooling conditions cause tremendous thermal and transformation stresses in the component and subsequently distortion. During HPGQ only convection takes place which results in much more homogenous cooling-conditions, see Figure 3.

Significant reductions of distortion by substituting Oil-quench with HPGQ have been published [9]. Another advantage of HPGQ is the possibility to adjust the quench-intensity exactly to the needed severity by choosing quench-pressure and quench-velocity. Typical quench pressures range from 2 bar to 20 bar. The gas velocity is controlled by a frequency converter and typical gas-velocities range from 2 m/s to 15 m/s depending on the part-geometry and the steel-grade of the component.

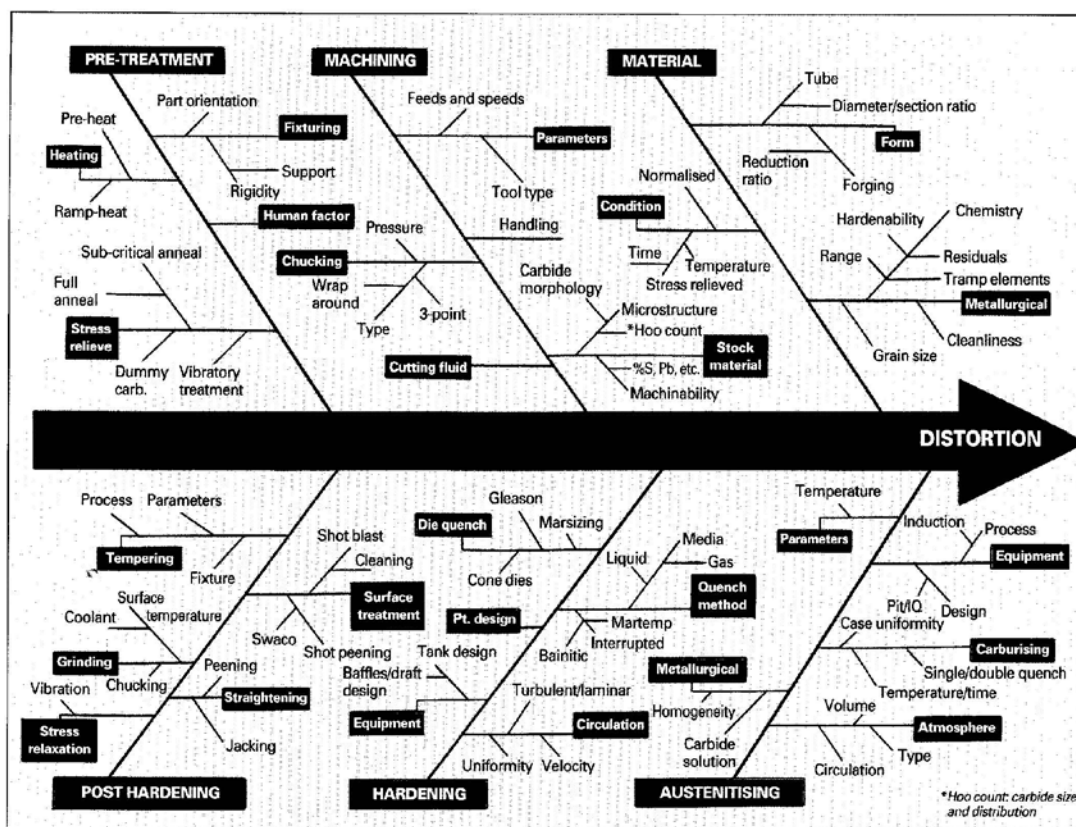


Figure 2. Potential factors influencing distortion of bearing-rings [2]

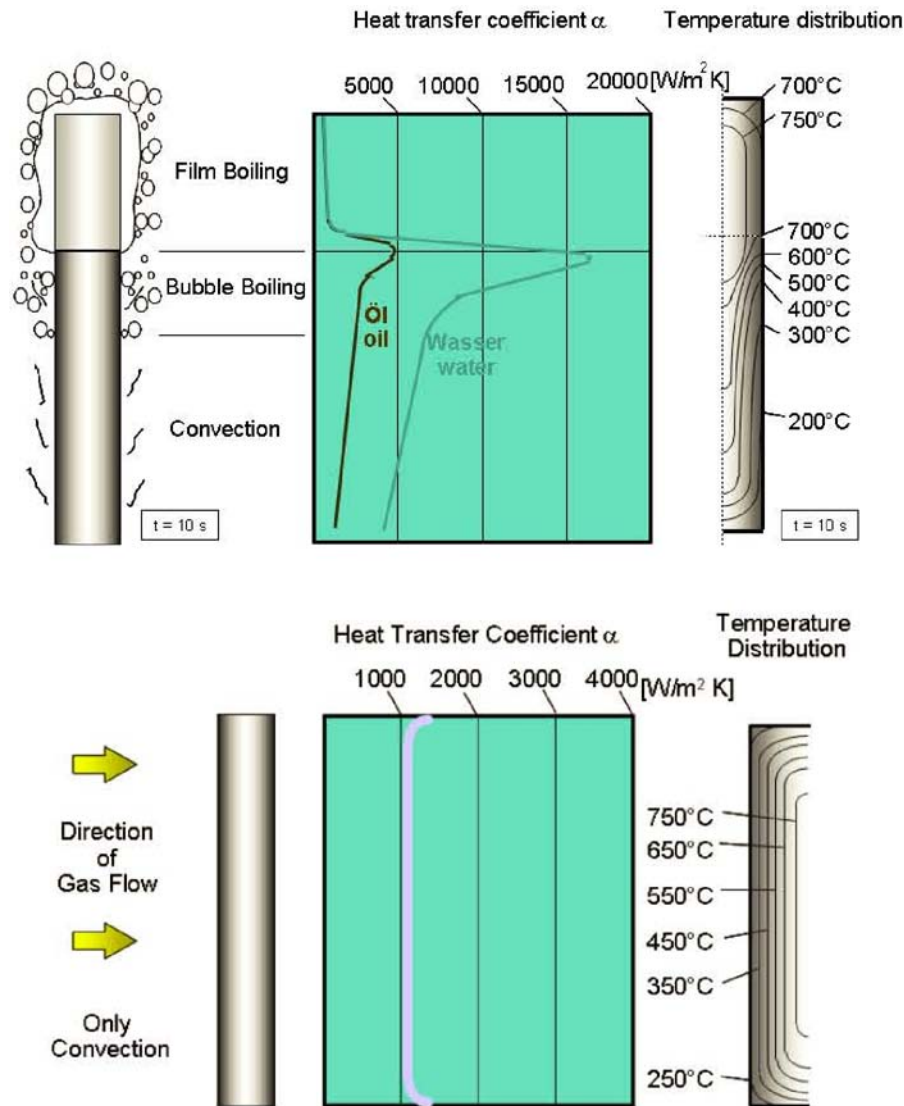


Figure 3. Heat transfer coefficient and temperature-distribution in liquid- and gas-quenching [3]

Equation 1 describes the heat transfer coefficient as a function of gas-velocity, gas density and the type of gas. [4]

$$\alpha = C w^{0,7} \rho^{0,7} d^{-0,3} \eta^{-0,39} c_p^{0,31} \lambda^{0,69} \quad (1)$$

where

- C constant factor (depending on quench cell);
- w gas velocity;
- ρ gas density;
- d diameter of component;
- η viscosity of the gas;
- c_p specific heat capacity of the gas;
- λ thermal conductivity of the gas

Typical gases applied for HPGQ are nitrogen and helium. [5]. To achieve the required core hardness in gears of low alloyed case hardening steels, helium as quenching medium and a gas pressure of 20 bar is necessary for many applications. The usage of this low density gas allows to quench with very high gas velocity by using reasonable motor power. In combination with an advanced gas-recovery technology, exhibiting a recovery rate > 99.5 %, gas quenching is very economic in spite of the helium gas price. The positive experiences with gas quenching have induced gear suppliers to use case hardening steels with better hardenability thus being able to quench bigger transmission-components as well.