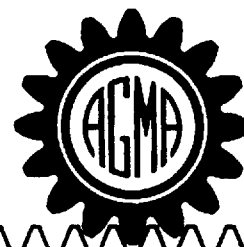


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Application of Ausforming to Gear Finishing – Process, Design and Manufacturability Issues

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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:

Ausforming is a thermomechanical process which integrates surface induction heating with precision hot gear roll finishing, and is capable of finishing spur and helical gears, thereby eliminating tooth-grinding and some associated operations. Gears are in the hobbed, carburized and hardened condition prior to ausform finishing. Ausforming involves controlled execution of the following four processing steps: (1) contour induction heating of the hardened gear tooth surface layers, followed by (2) rapid quenching of the gear in marquenching oil maintained at 300–450°F to achieve a metastable austenitic condition, (3) roll finishing of gear teeth in the metastable austenitic condition in the processing tank containing the hot marquenching oil, to final tooth dimensions using power-driven precision gear roll finishing dies, and (4) final quenching to martensite.

Ausforming is applicable to carburizing grade low alloyed steels, used in a broad spectrum of gear applications, as well as through-hardening steels. Potential benefits of ausforming as demonstrated on the existing single-die ausforming machine at Penn State include improved gear tooth accuracy up to AGMA 12, enhanced surface finish of 3 to 6 $\mu\text{in Ra}$, and improved metallurgical features such as ausform strengthening induced in the surface layers, finer grain microstructure, and higher compressive residual stresses on gear tooth surfaces. Metallurgical characterization of ausformed gear tooth surfaces and performance testing of ausformed surfaces is in process.

This paper discusses the potential applications of ausform finishing of spur and helical gears, including process design and related manufacturability issues. Ausforming can be applied for finishing of gears with bores, integral shaft gears, cluster gears, and double helical herringbone gears. Examples are presented describing the flexible tooling arrangements possible to process a variety of gear geometries. Implementation of ausforming for a given application requires integrated tooling design of the hob or shaper cutter to produce appropriate stock allowance for optimal roll finishing. Machine design, controls and material handling features of the production-capable double die gear ausform finishing machine currently being built are briefly described showing the flexibility in tool arrangements and processing of a variety of gear geometries.

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1. Introduction

Over the past several years, the US gear industry has encountered considerable challenges from the industrialized countries in Europe and far east. The competitive position of the US gear industry has been substantially weakened and the share of imports to the US gear market is continuing to rise.[1] Investment in gear machine tools and infrastructure in the US gear industry is steadily declining, and use of out-dated equipment and processes only worsens the problem of delivery times, quality and manufacturing costs.[2] There is a strong need for the development of new and improved gear manufacturing techniques and equipment to improve the competitive status of the US gear industry. The National Center for Advanced Gear Manufacturing Technologies (NCAGMT) at Penn State is developing innovative techniques in gear manufacturing and metrology to strengthen the technological base of the gear industry. One of the research and development programs in the area of advanced gear manufacturing is *Gear Finishing by Ausforming*. The ausforming process is capable of finishing case-hardened spur and helical gears to achieve improved strength accuracy, surface finish, and through-put production rates. In this paper, the process, and manufacturability issues involved in applying ausforming to the finishing of high performance transmission gears are discussed.

2. Ausforming Process Details

2.1 Process Description

Ausform finishing integrates three of the widely used gear manufacturing processes, namely, (1) induction heat treating, (2) martempering (also called marquenching), and (3) gear roll finishing, into a single in-line automated manufacturing operation which is capable of finishing spur and helical gears to AGMA quality rating of 12 or better.[4] Prior to ausform finishing, gears are

hobbed, carburized and hardened to specifications required for the service requirements. The ausform finishing process involves the following processing steps:

- Contour induction heating of the carburized surface layers of the gear teeth (including profile, fillet and root areas) to austenitize only the case region;
- Rapid quenching of the gear into hot marquenching oil maintained at 300 to 450°F to achieve a metastable austenitic condition in the carburized surface layers of the gear teeth;
- Precision gear roll finishing of the gear teeth in hot marquenching oil to final dimensions using master gear rolling dies and a feed-back controlled servo-hydraulic system;
- Final quenching of roll finished gear to 120-150°F for transformation of austenite to martensite.

The thermal excursion of gear tooth surface temperature during the above four processing steps involved in gear ausform finishing is shown schematically in a Time-Temperature-Transformation (TTT) diagram (Figure 1) for a typical carburizing grade low alloyed steel. It is important to note that gears must be in the carburized and hardened condition prior to ausforming in order to achieve the core properties, especially the combination of microstructure, hardness and toughness required. Ausform finishing is preferably performed prior to the tempering cycle. This facilitates optimization of the induction heating cycle and to ensure rapid solutionization of alloy carbides and complete austenitization of the gear tooth case region prior to the roll finishing step. Line a-b (Figure 1) represents the induction heating step of ausforming when the gear tooth surfaces are austenitized by heating to above the appropriate temperature. The induction heating cycle takes only 60 seconds to complete. It is optimized to ensure that the heat