Bevel Gear Manufacturing Troubleshooting

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BASIC GEARING DEFINITIONS*

- GEAR – The member with the larger number of teeth.
- PINION – The member with the smaller number of teeth.
- PITCH LINE RUNOUT is the total variation between high and low indicator readings of the amount of pitch line error as observed from a fixed reference point perpendicular to the axis of gear rotation. Runout readings include eccentricity and out-of-roundness of the pitch line.
- PITCH VARIATION is the difference between the pitch and the measured distance between the corresponding points on any two adjacent teeth.
- TOOTH CONTACT is the area on a tooth surface from which marking compound is removed when the gears are run together in a test machine.
- LAME CONTACT is a condition existing when the tooth contact pattern on one side of a tooth is nearer the top (or flank) than is the tooth contact pattern on the opposite side of the same tooth.

*(GLEASON WORKS, Testing and Inspecting Bevel and Hypoid Gears, 1979)

Abstract:

The quality of gearing is a function of many factors ranging from design, manufacturing processes, machine capability, gear steel material, the machine operator, and the quality control methods employed. This article discusses many of the bevel gear manufacturing problems encountered by gear manufacturers and some of the troubleshooting techniques used.

Introduction

A goal of all gear manufacturers is to have the ability to set up several different bevel machines, accurately duplicate a "production reference," and meet all quality requirements with a minimum amount of labor and scrap. This is true for cutting, lapping, and hard finishing of tooth profiles.

Some manufacturers have taken a major step in accomplishing this goal by the addition of today's new CNC cutting, lapping, skiving, and grinding equipment. However, the manufacturers that still use predominantly old mechanical bevel gear manufacturing equipment are much more susceptible to and likely to struggle with a wide variety of manufacturing problems.

The manufacturing of a desired quality level bevel gear set is a function of many factors, including, but certainly not limited to, design, manufacturing processes, machine capability, gear materials, the machine operator, and the quality control methods employed. In this article we will make some basic assumptions about the bevel gear design, engineering specifications, and the basic processes and concentrate mainly on the problems found in bevel cutting, heat treating, and hard finishing operations.

Assumptions

We want to concentrate primarily on bevel gear manufacturing problems that are encountered by manufacturers that frequently set up and produce a variety of bevel summaries on a repetitive basis. Therefore, we have made the following assumptions.

1. The bevel set design is good, tooth contact analysis programs have been run, and motion curves and displacement values are within desired parameters.

TABLE 1 – HYPOID/SPIRAL BEVEL GEAR & PINION SET PROCESSING

GEAR	PINION
FORGING	FORGING
PRE-TREATMENT NORMALIZE	PRE-TREATMENT NORMALIZE
BLANKING • Profile Turning • Broaching • Hole Drilling • Identification	BLANKING • Profile Turning • Splining • Green Grinding • Threading • Identification
TOOTH CUTTING • Machine Setup	TOOTH CUTTING • Machine Setup
GREEN TEST • Cutting Setup Approval • Size and Contact Comparison to Production "Ref." • Inspection	GREEN TEST • Cutting Setup Approval • Size and Contact Comparison to Production "Ref." • Inspection
BURRING, CHAMFERING	BURRING, CHAMFERING
HEAT TREAT • Carburize and Quench • Bore Size • Gear Geometry	HEAT TREAT • Carburize and Quench • Induction Anneal • Straightening
HARD GRIND • Bore I.D.	HARD GRIND • Bearing Journals

MATCH AND LAP OR HARD FINISH • *Refine Tooth Surfaces for Acceptable Tooth Contacts* and Noise Level

HARD TEST • Monitor Finishing Operation

PROTECT • Phosphate Coating for Break In, Rust Proofing, and Identification

SHIP • Assembly Line or Customer

2. The bevel set development has been completed, "production references" made, and finished gear set testing has been completed and found acceptable.
3. Engineering standards for bevel gear accuracies and tooth contact patterns have been set according to design and testing requirements.
4. The manufacturer has the gear set manufacturing processes to meet the engineering standards for bevel gearing.
5. In general, the gear manufacturing equipment is capable, and the work holding tooling is in good shape and to specifications.
6. Both pinion and gear blanks meet process specifications and are free of damage.
7. Material handling of pinions, gears, and gear sets throughout the manufacturing process is accomplished without damage.

General Bevel Set Processing

A general flow diagram of hypoid and spiral bevel gear processing is shown in Table 1. It lists the steps in the process and in what general order they normally would follow.

The Bevel Gear and Pinion Cutting Operations

Bevel gear and pinion cutting operations are by far the most critical of the bevel processing operations. When performed to meet the manufacturer's engineering specifications for tooth contact position and analytical tolerances, it will minimize the time and labor impact of all other post operations and maintain the highest level of intended gear set quality. This is also true for bevel sets that are processed for hard finishing operations. No matter what gear cutting system you use the majority of what is shown in Tables 2-7 should apply.

The Heat Treatment Operation of Gears and Pinions

Generally, most manufacturers experience a decrease in quality levels as their gears and pinions pass through the heat treat operations. On the

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average, the carburization and press quench process will decrease at least two levels in the AGMA rating tables.

The nature of the heat treat operation alters the geometry and microstructure of the "green" material. The areas of concern generally include flatness, roundness, taper, warpage, pockets, and straightness. The deterioration of gear accuracies has a negative impact on general gear quality, lapping, and hard finishing cycle times, and may cause potential warranty problems.

Hard Finishing of Gear and Pinion Tooth Profiles

These processes consist of grinding or hard carbide cutting the gear or pinion tooth profiles after the heat treat operations. This post heat treat operation offers us the ability to remove any heat treat distortions that may have occurred, as well as improves the gear tooth accuracy.

The Lapping Operation Of The Bevel Gear Set

The lapping of a bevel gear set should be no more than a minimal refining of the gear tooth surfaces for tooth contact shape, length, and noise level. In general, we should take a good quality gear set and make it even better.

Finish Grinding of Gears and Pinion Locating Surfaces

The hard grinding of critical mounting dimensions and bearing journals are as important to gear quality and life as the cutting operation itself. Engineering tolerances for runout, size, concentricity, and perpendicularity must be met.

Conclusion

We have attempted, in these few pages, to discuss the hypoid and spiral bevel gear set manufacturing process and to provide a general checklist that can be used to troubleshoot manufacturing problems when they occur.

Understanding the root causes of gear manufacturing problems is good prevention and also contributes to improved quality and productivity.

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TABLE 2 – THE GEAR CUTTING OPERATION

Problem	Checklist
• TOOTH CONTACT DUPLICATION	
• Vertical Position/Cross	• Improper Machine Settings • Arbor Dimension Error
• Vertical Position/Both Sides Heel or Toe	• Improper Machine Settings • Arbor Dimension Error
• Lameness	• Improper Cutter Sharpening • Wrong Pressure Angle Cutter • Cutter Gaging Error • Arbor Dimensions Error
• PITCH LINE RUNOUT	• Dirt/Chips • Improperly Mounted Workholding Equip. • Improperly Mounted Cutter • Clamping Pressure • Clamping Spring Size • Hydraulic Pressure • Work Piece Not Seated Properly • Overhead Bracket Support on Some Machines • Clamping Plate Size and Rigidity • Locating Plate/Expandisc Size
• PITCH VARIATION	• Index Plate Worn • Index Lock-up Pawl Worn • Stock Division Error by Operator • Mechanical Index Counter Error • Amount of Stock Left for Finish Cut • Bore Locator Undersize • Finish Cutter Cutting in Roughing Rootline • Drive Key Used

TABLE 3 – THE PINION CUTTING OPERATION

Problem	Checklist
• TOOTH CONTACT DUPLICATION	
• Vertical Position	• Machine Settings • Machine Difference • Wrong Cutter Point Diameter • Not Generated Out of Cut
• Pinion Cone	• Machine Center to Back • Ratio Roll Gear • Modified Roll Gearing • Tilt Setting • Wrong Pressure Angle Cutter • Improperly Ground Cutter • Cutting Collar Length
• PITCH LINE RUNOUT	• Arbor Not Seated • Arbor Not Built Properly • Blank Locating Surfaces • Cracked Collet or Oversize Nose Piece • Runout in Pinion Blank Locating Surfaces • Sliding Base Stop • Chucking Pressure
• PITCH VARIATION	• Collet Cracked • No Backlash in Mechanical Gearing • Sliding Base Positive Stop • Cradle Brake Needs Adjustment • Lubrication on Machine Gears • Too Much Stock Left from Rougher • Root Line Too Shallow and the Finish Cutter is Cutting in the Root • Finish Cutter is Too Deep and Cutting in the Rootline • Return Roll Centering Not Working Properly • Very Rough Surface Finish

TABLE 4 – HEAT TREAT CHECKLIST

Problem	Checklist
MAINTAINING GEAR GEOMETRY THROUGH HEAT TREAT	• Size is a Function of Case Depth and Gear Material • Quench Oil Temperature • Time from Furnace to Press Quench and Table Speed • Handling Equipment • Load Pattern Height, Stack Weight, and Spacers • Quench Oil Flow Rates • Dishing Cam "Zeroed" • Quench Ring Pattern and Alignment Key • Cleanliness of Oil • Type of Gear Steel • Nicks and Bumps on Gears • Lower Die Parallelism • Inner, Outer Ring, and Expander Pressure
MAINTAINING PINION GEOMETRY THROUGH HEAT TREAT	• Loading Pattern/Vertical Versus Horizontal • Straightening • Center Size • Cleanliness • Quench Oil Temperature

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TABLE 5 – GEAR & PINION FINISH GRINDING CHECKLIST

Problem	Checklist
GRINDING GEAR LOCATING SURFACES	
• Runout	• Pitchline Locators • Bore Size
GRINDING PINION LOCATION SURFACES	
• Runout	• Centers Damaged • Bearing Diameter Undersize • Concentricity
• Pinion Cone Position	• Amount of Grind Stock Removed From Thrust Surface

TABLE 6 – GEAR & PINION HARD FINISHING CHECKLIST

Problem	Checklist
• TOOTH CONTACT POSITION, LAMENESS, PITCH LINE, RUNOUT, AND PITCH VARIATION	• Refer to Cutting List and Substitute the Word Grinding Wheel for Cutter
• INTERFERENCE, GRINDING BURN	• Whole Depth of Wheel • Speeds, Feeds, and Grit Size • Amount of Coolant

TABLE 7 – LAPPING OPERATION CHECKLIST

Problem	Checklist
• TOOTH CONTACT	
• Vertical Position and Lameness	• Gear Set Spot Prior to Lapping • Machine Settings • Oscillation Speeds • Toe/Heel Cam Setting • Tester Setup • Lapping Backlash
• Interference Lines and Hard Spots In Tooth Contact Area, Scoring	• Pinion Rootline/Sliding Base • Toprem • Position of Compound Pipe • Lapping Grit Size • Contamination of Vehicle • Undersize Gear or Pinion Tooth • Nicks and Bumps
• PITCH LINE RUNOUT	• Workholding Tooling • Mounting of the Workholding Tooling • Gear or Pinion Locating Surfaces • Runout Cut into Gear or Pinion • RPM of Lapping Machine • Brake/Torque During Lapping • Tester Tooling and Setup
• PITCH VARIATION	• Not Likely to Occur