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Feature-Based Definition of Bevel Gears

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American Gear Manufacturers Association



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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

Bevel gears for many applications are subject to increasing levels of performance but with reduced cost. These factors have driven bevel gears toward sophisticated CMM control techniques. The complex shape of a bevel gear tooth surface must be defined mathematically for the CMM, but the mathematical definition tends to be difficult for direct use in gear design and manufacture. The mathematical definition may be condensed into a "feature-based" definition which is more convenient for gear design and manufacture. The feature-based definition may easily be described on the engineering drawings and subsequently toleranced to describe "fitness-for-use" boundaries. Development and application of the feature-based definition is described in this paper.

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American Gear Manufacturers Association
1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 1995

ISBN: 1-55589-660-X

FEATURE-BASED DEFINITION OF BEVEL GEARS

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Introduction

Bevel gear tooth shape has traditionally been controlled with contact patterns taken on the familiar roll test machine. Over the past few years, electronic coordinate measuring machine (CMM) techniques have been developed and applied to bevel gears. Each method has advantages and many manufacturers apply both.

Commercial bevel gear CMM techniques are available in the marketplace. These have been found to be lacking in several aspects of interest to meet Caterpillar's requirements. For these reasons, Caterpillar devised a bevel gear CMM "feature-based" definition technique.

The advantages of the feature-based definition include increased engineering design accuracy, better communication between engineering and manufacturing, improved understanding of heat treat distortions, data consolidation into a form manageable by statistical process control (SPC), and promotion of SPC techniques.

Development and application of the feature-based definition will be the focus of this paper. Contact pattern roll testing is unaffected; it will be treated minimally.

Caterpillar Gear Application

Caterpillar makes a wide variety of earthmoving machinery including tractors, wheel loaders, motor graders, off highway trucks, wheel tractor scrapers, etc. Modern products of this type are continuously subject to demands for higher reliability, longer durability, improved performance, yet lower cost. The track type tractor, for example (Figure 1), competes in the market only if, within stringent cost limits, it can provide reliable service and durability levels demanded by the customer. Such machines are further subject to government noise restrictions that routinely grow in severity. This means that all components must constantly improve, gears included.

Also of great significance to Caterpillar is the need for excellent world wide parts service support. Caterpillar has manufacturing plants in several locations throughout the world and, in some cases, bevel gears of the same part number are produced simultaneously in multiple facilities. These are distributed through the parts service system where mixing of the sources will occur. By company policy, the bevel gears must be interchangeable - as individual parts, without matched set requirements, and without lapping - regardless of origin of manufacture.

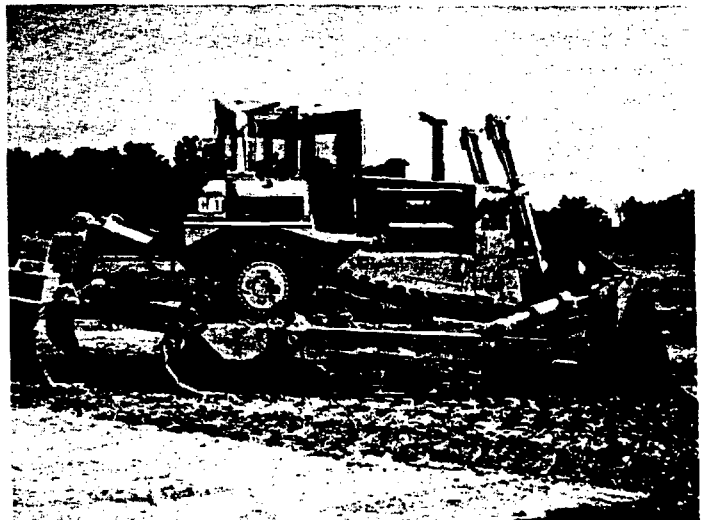


Figure 1. Modern track-type tractor

Why Develop CMM Techniques?

Higher demands on the bevel gears eventually led into field life and noise problems. Enough problems were occurring, along with the expense of warranty, that a joint team of engineering, manufacturing, and quality personnel was formed in the early 1980's to devise a solution.

At the time the team was formed, bevel gears were designed and manufactured the "old" way, that is, by the traditional methods built around control by the contact pattern roll check. Design was an approximate process based on experience with limited analytical accuracy. Engineering design information was minimal for the tooth shape; only a brief description of the contact pattern was provided. Manufacturing control was frustrated by the inevitable presence of heat treat distortion; settings and cutter geometry were changed at the direction of the manufacturing foreman to obtain the "correct" contact pattern. The entire process was, of course, highly subjective. Variable geometry was produced with limited understanding of the geometry and its effect on gear set stress and life.

The problems that surfaced were difficult to resolve. These appeared in the form of some parts that had difficulties for reasons that were not clear (Figure 2). A sporadic element was present as well; sometimes "good" jobs drifted to "bad" and others oscillated in and out of problem status. Generally, experimenting by persons with considerable experience was the only resolution technique and this was not always successful.

The team agreed that the best solution was to provide analytical inspection techniques for bevel gears. This was not without precedent: involute spur and helical gears were inspected with the analytical equipment of the familiar variety, and had been for many years [1].

Initial CMM Experience

The early experiments with CMM of bevel gears showed, for the first time, that routine shop adjustments caused significant geometry changes. Also, these showed considerable variation from heat treat effects. From these experiments, the following conclusions were drawn:

1. Analytical measurement was mandatory to allow management of bevel gear design and manufacture with modern technology.
2. This was in harmony with the rest of Caterpillar's manufacturing operation: no other component would even be considered for manufacture without the use of modern production technology.
3. Problem jobs, and associated manufacturing process decisions, could be explained with CMM inspection (Figure 3).

At that time, no commercial CMM systems were available so a decision was reached to proceed with CMM bevel gear analytical development at Caterpillar. Simultaneously, development was initiated for powerful FEA-based analysis tools.

CMM Application Philosophy

CMM methodology was a very big change from the long standing practice of contact pattern inspection. One could not expect just to "drop in" CMM inspection and have it go into effect; it was too different and no one knew exactly

PARTS LIST	TROUBLEMAKERS CAUSE:	WITH PATTERN CONTROL ONLY:
1A1XXX		
1A2 *	SCRAP	"DON'T KNOW WHY SOME PARTS CAUSE TROUBLE"
XXXXXX		
----	ADJUSTMENTS	

-----	DISRUPTION	

-----	WARRANTY	
XXXXXX		

* TROUBLEMAKERS

Figure 2. Parts with unclear reasons for difficulties

what to expect from a CMM system in the open manufacturing environment. To devise a system that would, in fact, be effective in the actual production mode required some planning. To meet the dual needs of design and manufacturing was, initially, a matter of establishing CMM application philosophy.

First was agreement of the specific application goals. CMM bevel gear inspection intentions would be to:

- A. Enhance design accuracy for the required loads in the vehicle operation.
- B. Provide manufacturing the ability to identify the process to meet the required tooth accuracy.
- C. Enable process control with SPC.
- D. Equate cause and effect.

Next was the establishment of a method approach for modern production technology requirements [2]:

- A. Conformance to an objective standard.
- B. Capability based tolerances.
- C. Manufacturing process control.

And then a method approach for process control:

- A. Evaluate the actual level of conformance.
- B. Compare this actual level with the standard.
- C. Take corrective action if required.

BACK TO THE PARTS LIST:

PARTS LIST

1A1XXX
1A2 *
XXXXXX

XXXXXX

* TROUBLEMAKERS

WITH CMM:

WHY TROUBLEMAKERS?

1. PROCESS COULD BE DRIFTING
 - DATA HELPS MONITOR
 - ADJUST PROCESS VIA SPC
2. DESIGN INAPPROPRIATE FOR PROCESS
 - OPTIONS:
 - a. REDESIGN
 - b. MOVE TO BETTER PROCESS

Figure 3. Parts with difficulties explained by CMM inspection