Systematic Analysis of Gear Failures

Lester E. Alban

Systematic Analysis of Gear Failures

Lester E. Alban
Metallurgical Engineer
Fairfield Manufacturing Company, Inc.
Subsidiary of Rexnord, Inc.

American Society for Metals
Metals Park, Ohio 44073

Library of Congress Catalog Card Number: 85-70125
ISBN: 0-87170-200-2
SAN: 204-7586

PRINTED IN THE UNITED STATES OF AMERICA

Preface

From the discovery of the failure to the final letter of transmittal, the line of communication should remain open, accurate, and sincere. There is no other way to achieve an acceptable plan for corrective action.

Not only the title of this book, but the entire contents strongly emphasize the systematic approach to an analysis of the problem. Putting the complete picture in a sequential pattern makes sense. Case histories are good, but they often do not detail the methods used to determine the final answer. All too frequently a person views a gear failure, finds a similar picture in a book, and believes it to be of the same mode and cause; this may not be so.

The purpose of this text is to train the reader in the art of discipline, to establish a logical step-by-step system of analysis: begin at the beginning and continue methodically to the end. If only we can influence field personnel, field representatives, mechanical and metallurgical analysts, and responsible engineers in management to be aware of the overall picture and to appreciate the role each plays in the final analysis, this book will be a success.

No work of this extent is accomplished by the author alone. Not only has 36 years of first-hand experience been necessary, but also the experience of many experts in our peer group. Of course, Fairfield Manufacturing Company, now a subsidiary of Rexnord, Inc., has been uppermost in supplying the environment of quality reputation necessary to maintain a consistently ethical leadership. My first employer, the late Harrold J. Bates, was meticulous in his concern for detail and accuracy. We

learned to orient all our efforts toward the needs of our customers. This training has been good, and this philosophy continues.

Since I retired a year ago, Fairfield has graciously supplied an office for my use while writing. The Metallurgical Department, under the direction of R. L. Hughes, has been exceptionally patient and extremely helpful in allowing me full use of its time, talent, past records, photographic ability, and laboratory facilities, and sometimes just by listening. Without the stenographic help of its secretary, this work would have been almost impossible. My wife, Faye, was always encouraging and really didn't believe I had retired a year ago, since I always went to work at the same time every morning. This has been a work of discipline, but possible only with the help and the faith of those mentioned above.

Contents

CHAPTER 1

Basic Understanding of Gears

Analyzing a failed part without taking into account the entire picture of magnitude and direction of applied forces, the spacial relationship of all component parts within the assembly, and the environmental conditions existing around the unit would be like examining a torn automobile tire for defects but never examining the bent axle that was causing the detrimental side thrust. For a systematic study of a gear failure, the basic parameters of a gear must be understood.

Purpose, Design, Function

A gear is a machined component that transmits motion and force from one element in a working unit to another element in the same unit or to another working unit in either the same plane and direction or a completely different plane or direction. The force, due to this transmission, may either increase or decrease in power from one element to the next. Design and function are closely associated because a gear is designed with a specific function in mind. The question is if this gear will perform the function that was intended by the designer.

Spur gear and pinion. A spur gear and pinion (Fig. 1-1) is a parallel-axis unit with tooth forces and motion at exactly 90°

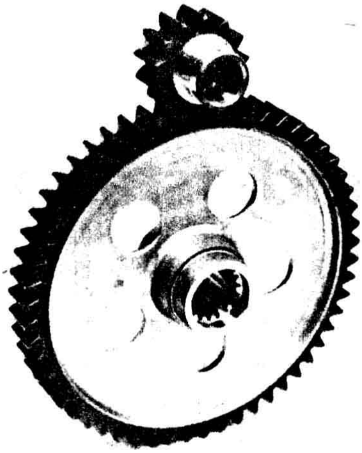

Fig. 1-1. Spur gear and pinion.

from the central axis of each part. Due to the ratio of numbers of teeth in each part, the speeds may be increased or decreased. The transmission of power is in a straight line.

Helical gear and pinion (Fig. 1-2) is also a parallel-axis gearing application with transmission of power about a straight line. However, the teeth, being helical, exert a resultant force in an angular direction at the tooth contact interface in proportion to the angle of helix. Along with any tendency to move the tooth laterally by the applied contact pressure, there is also the tendency for a surface sliding action in the same direction. A double-helical gear is one in which two sets of helical teeth are

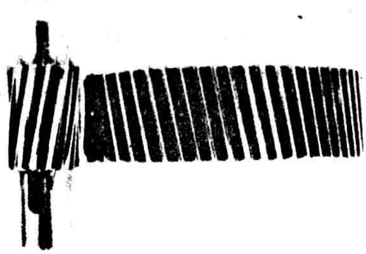

Fig. 1-2. Helical gear and pinion.

cut around the same periphery, but with an opposing angle of helix. The central area is machined out so that each portion is disconnected. If the central portion is securely connected, a herringbone gear will be obtained. The advantage to the double-helical and/or herringbone gears is that the side thrust common to the single helix has been eliminated.

Internal gear. Both the spur gear set and the helical gear set may be designed so that the gear member will have the teeth on the inside diameter of a ring. This is called an internal gear (see Fig. 1-3).

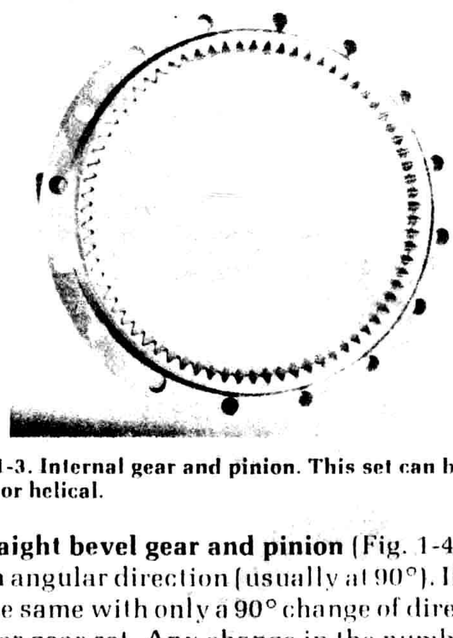

Fig. 1-3. Internal gear and pinion. This set can be either spur or helical.

The straight bevel gear and pinion (Fig. 1-4) will transmit motion in an angular direction (usually at 90°). If the speeds are to remain the same with only a 90° change of direction, the set is called a miter gear set. Any change in the number of teeth will change speed as well as direction. The contact forces tend to push the opposing teeth apart as well as to cause a lateral slide along each tooth surface.

Spiral bevel sets. As the off-angle gear teeth are given an angular displacement, they naturally assume a spiral (circular) shape to conform to the rotating motion. This gearing is called

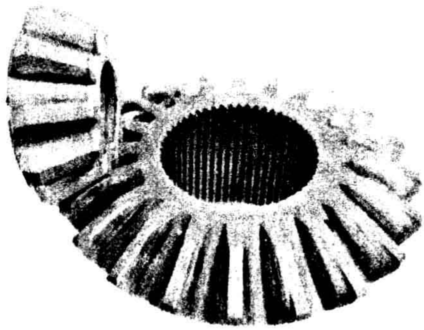

Fig. 1-4. Straight bevel gear and pinion.

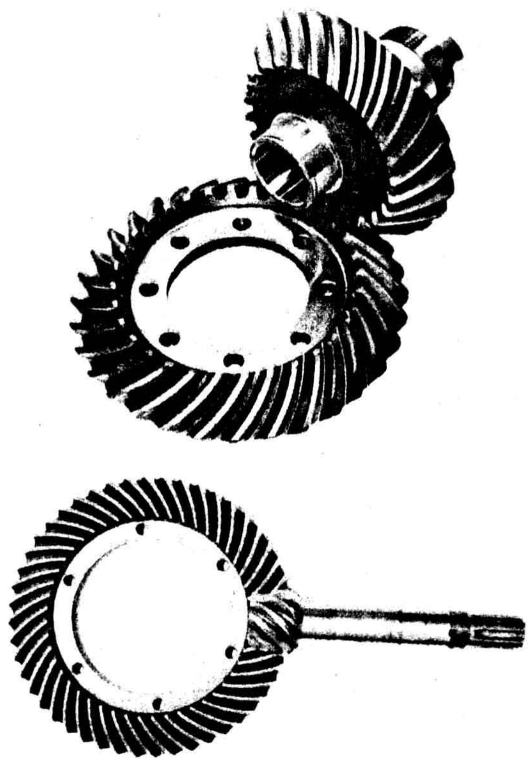

Fig. 1-5. Two types of spiral bevel sets, consisting of spiral bevel gear and pinion.

spiral bevel sets. There are many types of spiral bevel configurations; two types are shown in Fig. 1-5.

Hypoid sets. Usually the axis of the spiral bevel gear and pinion will intersect at a common point in space. However, when the pinion axis is raised or lowered in relation to the gear axis, the result is a hypoid set (Fig. 1-6). When the axis of the pinion is displaced almost to the center of the gear teeth at the periphery, the number of teeth in the pinion decreases to three or less and has the action of a worm pinion. This set is called the high-ratio hypoid set (Fig. 1-7).

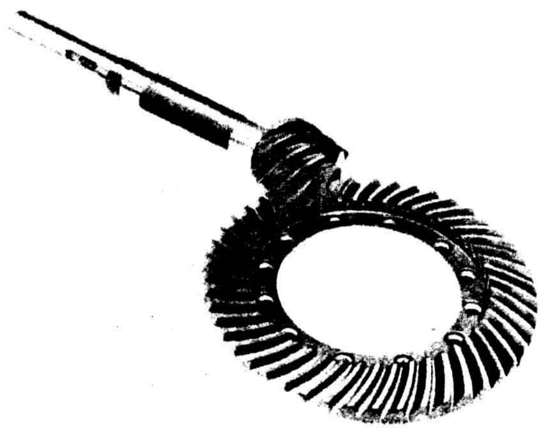

Fig. 1-6. Hypoid gear and pinion set.

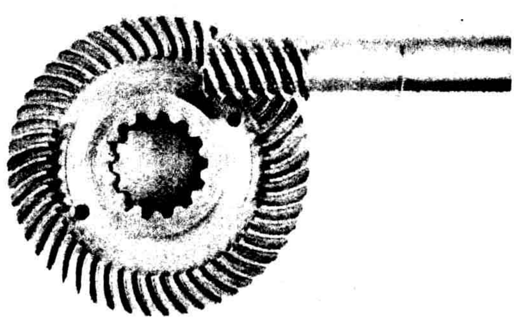

Fig. 1-7. High-ratio hypoid set.

Basic Applied Stresses

The loads applied to one tooth by the action of its mating tooth are at any moment of time a line contact at the most; or, at the least, a point contact. As the loads are increased, the line may lengthen or even broaden, or the point may expand to a rounded area.

The basic stresses applied to a gear tooth include the six types listed in Fig. 1-8; often, a combination of two or three types are applied at a time. Commonly they are tensile, compressive, shear (slide), rolling, rolling-slide, and torsion. Each type of gear tooth will have its own characteristic stress patterns.

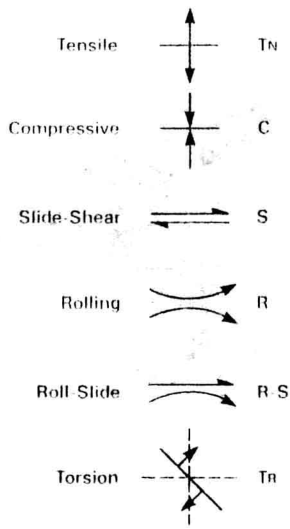

Fig. 1-8. Basic stresses that are applied to gear teeth. Often, two or three are simultaneously applied to a specific area.

For specific gearing terminology and nomenclature of tooth elements, refer to "Geometry and Theory of Gears" by Paul M. Dean[1,2] and Standards published by American Gear Manufacturers Association.[3]

Spur Gear

As the contacting tooth moves up the profile of the loaded tooth, a sliding-rolling action takes place at the profile interface. At the pitchline, the stresses are pure rolling. Above the pitchline, the rolling-sliding action again takes over, but the sliding will be in the opposite direction. Keep in mind that the action on the profile of the contacting tooth is exactly the same as the loaded tooth except in reverse order (see Fig. 1-9). The

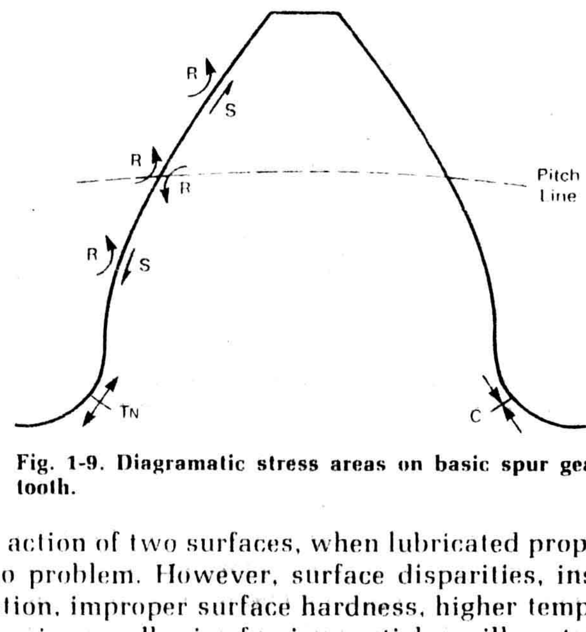

Fig. 1-9. Diagramatic stress areas on basic spur gear tooth.

sliding action of two surfaces, when lubricated properly, will have no problem. However, surface disparities, insufficient lubrication, improper surface hardness, higher temperatures, and abrasive or adhesive foreign particles will contribute to a breakdown during a sliding contact. At the same time, there is a tensile stress at the root radius of the loaded side of the tooth and a compressive stress at the root radius of the opposite side.

Helical Gear

The helical gear tooth receives the same contact action as the spur gear; i.e., a rolling-sliding action from the lowest point

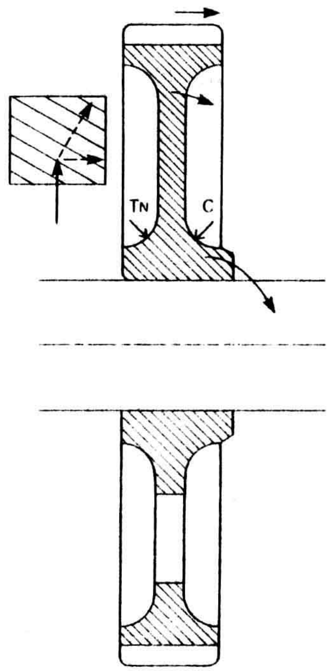

Fig. 1-10. Secondary stresses set up in associated parameters of a helical gear due to the side thrust action of the helix.

of active profile up to the pitchline, rolling over the pitchline, then sliding-rolling from the pitchline over the addendum. An additional stress is being applied to the helical tooth; a lateral sliding action is applied at all contact levels, including the pitchline. The force component at 90° to the direction of rotation increases as the helical angle increases. Resultants of this side thrust are often overlooked (see Fig. 1-10). The web between the center shaft hub and the outer gear rim is constantly undergoing a cycle of bending stress; it is not uncommon for a relatively thin web to fail in bending fatigue. If the hub of the gear faces against a thrust bearing, the bearing itself is under a constant thrust load. The shaft carrying the gear undergoes a continual rotation bending stress. It is also not uncommon to have such a shaft fail by rotational bending fatigue. The above