ADVANCED GEAR MANUFACTURING AND FINISHING

Classical and Modern Processes

Kapil Gupta
Neelesh Kumar Jain
Rudolph Laubscher

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Addresses all of the latest technologies important to the manufacture of gears.

- Covers the basics of gear engineering, conventional and advanced gear manufacturing and finishing, surface property enhancement, mechanical and case-hardening, and measurement of gear accuracy by analytical and functional inspection techniques
- Describes the machining systems, main components and working procedures, supported with diagrams and images
- Demonstrates the mechanisms and capabilities of new methods, and improvements to a range of gear manufacturing and finishing technologies
- Provides a critical review of recent research relating to gear manufacturing technologies

Advanced Gear Manufacturing and Finishing: Classical and Modern Processes offers detailed coverage of advanced manufacturing technologies used in the production of gears, including new methods such as spark erosion machining, abrasive water jet machining, additive layer manufacturing, laser shaping, and sustainable manufacturing of gears.

Industry is constantly producing new settings where gears must endure ever increasing stresses, strains, and temperatures. Advanced methods in manufacturing, finishing, and surface property enhancement have emerged in recent years to meet these challenges. The book examines the state-of-the-art research into these new methods, and considers the latest improvements to classic technologies in both gear manufacturing and finishing.

This book is essential reading for researchers and engineers working in the fields of powertrain manufacturing, gear technology, and advanced manufacturing technologies.

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Advanced Gear Manufacturing and Finishing

Preface

Gears and the associated gear manufacturing industry maintain a unique but significant position in the manufacturing sector at large. Almost every manufacturing industry utilizes gears and/or gear assemblies in one form or the other as part of their manufacturing process. The gear industry is not immune to technological advancement and requires new processes and techniques to fulfill the requirements of new and unique specialized transmissions that are being developed all the time. This development of new and novel techniques along with the advancements in the conventional processes needs to occur within the framework of quality, productivity, and ecological impact.

The aim of this book is to provide a concise collection of research and development aspects, salient features, applications, process principles and mechanism of advanced gear manufacturing processes.

It consists of seven chapters that include an introduction to gear engineering, conventional and advanced gear manufacturing and finishing processes, surface modification of gears, and eventually concludes with a chapter on gear metrology. Chapter 1, Introduction to Gear Engineering, introduces gears, their history, classification and type, important terminology, materials, and their manufacture. Chapter 2, Conventional Manufacturing of Cylindrical Gears, discusses conventional manufacturing of gears in brief. Chapter 3, Manufacturing of Conical and Noncircular Gears, provides an overview of conventional manufacturing of conical and non-circular gears. Chapter 4, Advances in Gear Manufacturing, is dedicated to advances in gear manufacturing and thus discusses laser machining, abrasive water jet machining, spark erosion machining, various additive processes including additive layer manufacturing, LIGA, and sustainable manufacturing of gears in more detail. Conventional and advanced gear finishing processes are presented in Chapter 5, Conventional and Advanced Finishing of Gears. Surface property enhancement techniques inclusive of gear coatings are the main focus of Chapter 6, Surface Property Enhancement of Gears. The book concludes with Chapter 7, Measurement of Gear Accuracy, where the gear metrology is presented and discussed.

The main audience targeted for this book is researchers, engineers, technical experts, and specialists working in the area of gear manufacturing and finishing.

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Chapter 1

Introduction to Gear Engineering

1.1 INTRODUCTION AND HISTORY OF GEARS

1.1.1 Introduction

A gear is basically a toothed wheel that works in tandem with another gear (or gears) to transmit power and/or motion to change speed and/or direction of motion. Dudley defined a gear as "a geometric shape that has teeth uniformly spaced around the circumference and is made to mesh its teeth with another gear" [1]. Slipping is a major problem during transmission of motion and power between two shafts by rope or belt drive and consequently may affect the precision and efficiency of the system adversely. This slipping phenomenon is largely avoided by means of gear drives. The compact layout, flexibility, high efficiency, and reliability are the most important features that make gears and gear drives the first choice in many applications. Gear sizes range from nanometers (nanogears) to meters (macrogears) with corresponding application areas from nanoelectromechanical systems (NEMS) to large mills and wind turbines. A wide range of materials ranging from plastics and ceramics to ultrahigh strength steels are used in gear manufacture.

Gears and subsequently the gear manufacturing industry plays an integral role in many industrial sectors as it is one of the basic mechanical components used for transmission of motion and/or power in equipment, machines, and instruments. Several conventional and advanced methods of gear manufacture are available for use in specialized applications to produce gears that are fit for purpose. Technological advancements in gear engineering over the last few decades have enabled the gear industry to produce near-net shaped and high-quality gears by short process chains and a lower environmental footprint.

1.1.2 History

The writings of Aristotle (4th century B.C.) reflect some of the earliest reference to gears and their use [2]. He specifically noted that the direction of rotation is reversed when one gear wheel drives another. Water-lifting devices, in the form of 'Persian wheels', were used in the 3rd century B.C. Animals such

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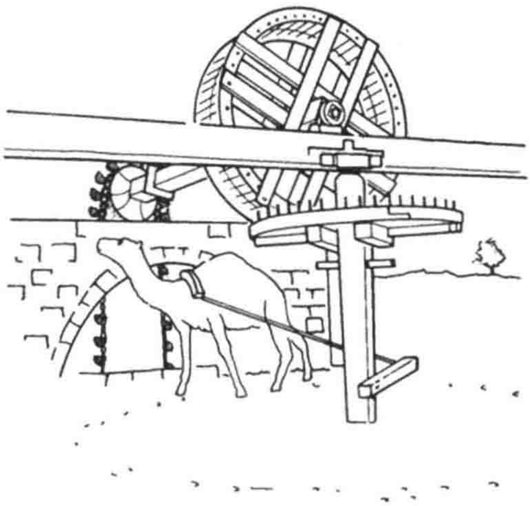


FIGURE 1.1 'Persian wheel': A water-lifting gearing mechanism used during 3rd century. *Source: Reproduced with permission from P.L. Fraenkel, Water lifting devices, FAO irrigation and Drainage Paper 43, Corporate Document Repository, Food and Agriculture Organization of the United Nations, Rome, 1986 [4].*

as camels, bullocks, and buffaloes were used to drive these devices that were typically associated with open wells. In this arrangement, an animal driven horizontal toothed wheel was meshed into a vertical toothed wheel that was then used to lift water containers that were attached to another geared mechanism (Fig. 1.1). Later on, this method was successfully adopted for use in water-driven grain mills and other devices. During the 3rd century, Archimedes also developed a device (Antikythera mechanism) that was equipped with numerous gears to simulate positions of astronomical bodies [3]. The sketchbooks of Leonardo da Vinci, dating to the mid 1400s, depict various unique gear mechanisms. Initially, wood was the material of choice for gear manufacture until it was subsequently replaced by cast iron.

A more advanced approach to gear engineering came into being at around 1400 with more comprehensive use of science and mathematics in gear design and the associated mechanisms. The first major investigation into gear design as regards to proving the benefits of the involute curve over a cycloidal was conducted by Philip de la Hire in France and later confirmed by a Swiss mathematician Leonard Euler who was responsible for the law of conjugate action [1]. The industrial revolution in England during the 18th century led to the use of cycloidal gears for clocks, irrigation devices, water mills, and powered machines. Further uses were rapidly developed and explored with the invention of the locomotive, vehicles, and other machines. Gear hobbing and shaping technologies were developed in the early 19th century providing the foundation for fabrication of better quality commercial gears. Various new gear types, materials, and surface treatment techniques were introduced during the 19th century. Further advancement in gear manufacturing, measurement techniques, and testing technologies during the late 19th and in early 20th centuries led the way for significant growth in its application in industry.

1.2 CLASSIFICATION AND GEAR TYPES

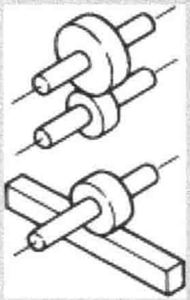
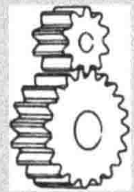
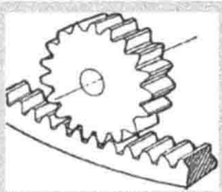
A wide range of gear types exist to fulfill various different application requirements. Gears and gear systems are usually classified according to the orientation/arrangement of its associated rotational axes. Gears are therefore classified as parallel-shaft gears, intersecting-shaft gears and nonparallel nonintersecting-shaft gears (refer Table 1.1). The details regarding these three categories and the corresponding gear types are discussed in detail in the following subsections.

1.2.1 Parallel-Shaft Gears

The first and most common class of the gear is where the shaft axes are in the same plane and parallel to one another. The gear teeth may be either cut straight (spur gear) or inclined (helical) and may be of either external or internal configurations. These gears can be either cylindrical or linear-shaped gears, and are used in three main transmission arrangements: External, internal, and rack and pinion.

Spur gears are one of the most extensively used types of parallel-shaft gears. These gears have straight teeth cut parallel to the shaft axis. Engagement by spur gears occurs between two parallel shafts or between a shaft and a rack. The larger of two engaged gears are referred to as the 'gear,' while the smaller is referred to as the 'pinion' regardless of which gear is being driven or acting as the driver. The external configuration of spur gears implies that the driver gear rotates in an opposite direction to the driven gear. A **rack-and-pinion** configuration is a special category of parallel-shaft gears, where transmission occurs by meshing a rack (shaftless linear-shaped gear) and a pinion (cylindrical gear wheel). The rack-and-pinion configuration is extensively used in machine tools and other devices to convert linear motion into rotary motion and vice versa. A **spur rack** is essentially a gear wheel with an infinite radius (Fig. 1.2) that engages a spur gear (pinion) with any number of teeth. An internal spur gear is made with the teeth cut on the inside face of a cylindrical gear which engages with an externally configured gear of matching teeth pattern with both rotating in the same direction (Fig. 1.3). The internal gear is usually referred to as the ring gear or annulus and is often used in planetary gear systems. The best functional performance requires that the diameter of ring gear be at least 1.5 times that of the mating external gear.

TABLE 1.1 The Three Major Categories of Gear Classification and Corresponding Gear Types

Categories of Gears (Based on the Orientation of Gear Shafts)	Types of Gears	Representation	Features, Applications and Methods of Manufacture
Parallel-shaft gears 	**Spur gears**		Features: Simple to design and manufacture, highest efficiency, easy to assemble, offer excellent precision, high wear and noisy operation
			Applications: Automotive transmission; Industrial drives; Machine tools; Motors and pumps; Agriculture equipment; Scientific instruments; Electronic devices; Large mills
			Methods of Manufacture: Hobbing, shaping, milling, broaching, casting, extrusion, stamping, powder metallurgy, forging, rolling, grinding, shaving, lapping, honing
	Helical gears		Features: High strength, smooth action, silent operation, offer good precision, axial thrust complications
			Applications: Automotive transmission; High-speed drives and machines; Rolling mills; Robotics; Agricultural equipment
			Methods of Manufacture: Hobbing, milling, shaping, casting, extrusion, stamping, powder metallurgy, forging, rolling, grinding, shaving, honing, lapping
	Rack and pinion		Features: Efficiently convert rotary motion to linear and vice versa; Flexibility
			Applications: Materials handling, linear actuators, power-steering system, machine tools, traveling gantries, robots, positioning systems, stair lifts
			Methods of Manufacture: Milling, shaping, broaching, casting, grinding, shaving, honing