PREFACE

Cam-follower systems are an extremely important and ubiquitous component in all kinds of machinery. It is difficult to find examples of machinery that do not use one or more cams in their design. Cams are the first choice of many designers for motion control where high precision, repeatability, and long life are required.* All automotive engines depend on cams for their proper valve function. Most automated production machinery uses cams extensively.

The design and manufacture of cams has changed dramatically in recent years. The development and proliferation of computers in engineering design and of numerical control in manufacturing have completely changed the process of cam design and manufacturing, and very much for the better. Until about the late 1960's cams were designed only by manual graphical layout techniques, manufactured in low quantities by manually controlled machining methods and in high quantities by analog duplication of a hand-dressed master cam. The subtleties of the effects of higher derivatives of the cam's chosen mathematical function were often ignored, due either to ignorance of their importance, or the inability to accurately determine their effects given the lack of computational facilities available at the time.

Currently, it is virtually universal and also very economical to use computer-aided engineering and design techniques to create cam geometry, including proper consideration of the effects of higher derivatives, and also to make the cam with high precision using continuous numerically controlled milling, grinding, or electrical discharge machining (EDM) equipment. A significant number of fundamental research results on the subject of cam design and manufacture have been published in recent years. This book is intended to provide a definitive reference for the design and manufacturing of cam-follower systems by bringing up-to-date cam design technology and cam research together between a single set of covers for the benefit of the design and manufacturing engineering community.

The book takes the subject from an introductory level through advanced topics needed to properly design, model, analyze, specify, and manufacture cam-follower systems. Beginning with a description of "how not to design a cam" in order to point out pitfalls that may not be obvious to the beginner, the proper way to design a cam for multiple and single-dwell situations is developed in detail. All the acceptable (and some unacceptable) classical cam functions are described and their mathematics defined for the common double-dwell application. Polynomial functions are introduced and used for both double- and single-dwell examples. Problems with polynomial cams are defined in detail and ways to design around these problems are discussed. Spline functions are introduced as a class of cam motion functions that can solve the most difficult cam design problems. Many examples are developed to show how splines, especially B-splines, can solve otherwise intractable cam design problems.

The issues of cam pressure angle and radius of curvature are fully addressed for various types of cams and followers: radial, barrel, translating, and oscillating, roller and

* Some machines use pneumatic devices for motion control rather than cams. The former have poor dynamics and accuracy compared to cam-driven machines.

flat-faced. The dynamics of the cam-follower system are introduced along with techniques for modeling the follower system as lumped parameters. Both the inverse dynamic (kinetostatic) and forward dynamic solutions are developed for a multiplicity of models of various degrees of freedom. The extensive literature on these topics is referenced in the bibliography. Residual vibrations in the follower train are addressed along with a number of cam functions that can reduce the level of vibration. Polydyne and splinedyne cams are defined and methods for their calculation described.

Calculations for the cam contour of radial and barrel cams with translating and oscillating roller or flat followers are defined. Cutter compensation algorithms and cam surface generation are defined for all common cam-follower configurations. Conjugate cam calculation is defined as well. Cam materials and manufacturing techniques are described and recommendations made.

Stress analysis of the cam-follower joint is presented in detail along with methods to determine the failure modes of typical cam/follower materials in surface contact under time-varying loads. Lubrication of the cam-follower interface is also addressed as is wear.

Methods for the experimental measurement of acceleration, velocity and displacement of cam-follower systems are described, and examples of such measurements taken on operating machinery are shown. Case studies from automotive and automated manufacturing machinery are presented.

Accompanying the book on CD-ROM is a limited-time trial demonstration copy of the Professional Version of program DYNACAM for WINDOWS V 7.0, written by the author. This program will solve most of the equations described in the book and allows (in its fully licensed version) the design, dynamic modeling, analysis, and generation of follower center, cam surface, and cutter coordinate data for any cam. It also defines conjugates for any cam design. Also included are limited-time trial demonstration versions of programs FOURBAR, SIXBAR, and SLIDER that allow the design and analysis of cam-driven linkages.

The author would like to express his sincere appreciation to Dr. Ronald G. Mosier who wrote Chapter 5 on spline functions and checked many of the equations in other chapters. Also, Dennis Klipp of Klipp Engineering, Waterville, ME, Paul Hollis of Tyco Electronics Corporation, Harrisburg, PA, R. Alan Jordan of Delta Engineering, Muncie IN, and Dr. Thomas A. Dresner, Mountain View, CA provided welcome and helpful comments on the book during its development. Many other people reviewed sections of the book or supplied data, illustrations, and information used in the book. I would like to especially thank Gregory Aviza, Al Duchemin, Charles Gillis, Robert Gordon, Joel Karsberg, Thomas Lyden, Corey Maynard, Edwin Ryan, Edward Swanson, and John Washington, all of the Gillette Company, Boston, MA, and Arthur Borgeson of Borg Engineering, Hanson, MA. Finally, the author thanks his editors at Industrial Press, John Carleo and Janet Romano, for making this the most pleasant and productive book development process yet experienced.

Every effort has been made to ensure that the material in this book is technically correct. If any errors remain, the author takes full responsibility, and will greatly appreciate their being pointed out to him. Please contact him by email at norton@wpi.edu or norton@ designofmachinery.com if you discover any errors in the text or in the accompanying programs. Information on book errata and program updates can be found at http://www.designofmachinery.com.

Robert L. Norton
Mattapoisett, Mass.
August, 2001