

Preface

Lead screw drives are used in various motion delivery systems ranging from manufacturing to high precision medical devices. Lead screws come in many different shapes and sizes; they may be big enough to move a 140 tons theatre stage or small enough to be used in a 10-ml liquid dispensing micro-pump. Disproportionate to the popularity of lead screws and their wide range of applications, very little attention has been paid to their dynamical behavior. Only a few works can be found in the literature that touch on the subject of lead screw dynamics and the instabilities caused by friction. This monograph aims to fill this gap by presenting a comprehensive study of lead screw dynamics focusing on the friction-induced instability in such systems.

This book is based partly on the first author's Ph.D. research at the University of Waterloo, Ontario which was carried out under the supervision of the second author. The need for a dedicated and detailed study on the friction-induced vibration in lead screws became evident to the authors when they encountered two lead screw noise problems – over a short period of time – from two very different commercial applications which shared many resemblances. One of these two cases is discussed in Chap. 9.

After a brief introduction to the topic of friction in machines and mechanisms in Chap. 1, some basic information regarding lead screws are presented in Chap. 2. In this chapter, the kinematic relationship between lead screw and nut and the contact forces are introduced which serve as the basis for the mathematical models of Chap. 5. Some mathematical background topics are reviewed in Chap. 3. Included in this chapter is a brief introduction to the mathematical tools used throughout this book; namely, the eigenvalue analysis method and the method of averaging.

Friction can cause instability in dynamical systems through three distinct mechanisms: (1) negative damping, (2) kinematic constraint, and (3) mode coupling. Chapter 4 is dedicated to the introduction of these mechanisms. Illustrative examples are worked out in this chapter to demonstrate the techniques that are applied to the lead screw drives in the later chapters.

A number of mathematical models are developed for lead screw drive systems in Chap. 5. Starting from the basic kinematic model of lead screw and nut, dynamic

models are developed with varying number of degrees of freedom corresponding to the different components of a real lead screw drive from the rotary driver (motor) to the translating payload. In these models, dry friction between meshing lead screw and nut threads constitute the sole source of nonlinearity.

Chapters 6–8 are the three main thrusts of this monograph. Negative damping instability mechanism is treated in Chap. 6. Using a 1-DOF dynamic model of a lead screw drive, the destabilizing effect of decreasing coefficient of friction with relative sliding velocity between meshing threads is discussed in detail. The method of first-order averaging is used in this chapter to expand the results of the linear eigenvalue analysis and to explore the existence and stability of periodic solutions. In Chap. 7, the mode coupling instability mechanism in lead screw drives is considered. A number of multi-DOF models – developed in Chap. 5 – are used in this chapter to explore the conditions under which vibrations (due to mode coupling) can occur in a lead screw drive system. The kinematic constraint instability is the subject of Chap. 8. Based on the results of Chap. 4, the connection between the well-known Painlevé paradoxes and instability is highlighted. In this chapter, parametric conditions for the onset of kinematic constraint instability are derived.

A practical case study is presented in Chap. 9 where friction-induced vibration in a lead screw drive is the cause of excessive audible noise. Using a complete dynamical model of this drive, a two-stage system parameter identification and fine-tuning method is developed to estimate the parameters of the velocity-dependent coefficient of friction model. The verified mathematical model is then used to study the role of various system parameters on the stability of the system and on the amplitude of vibrations. These studies lead to possible design modifications that can solve the system's excessive noise problem.

The current work provides a detailed treatment of the dynamics of lead screw drives and the friction-induced vibration in such systems. The reported findings regarding the three instability mechanisms and the friction parameters identification approach can improve the design process of lead screw drives.

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