Book review

Optimal Protection from Impact, Shock, and Vibration, by D.V. Balandin, N.N. Bolotnik and W.D. Pilkey, Published by Gordon and Breach Science Publishers, 2001.

Shock and vibration isolation is a well-developed engineering discipline, and every engineer who practices it should strive to make his designs optimal in some respect. As design requirements grow and practical technologies become more and more sophisticated, a book that outlines basic mathematics and mechanics of this discipline is extremely welcome.

The authors cover ground from rigorous, even abstract, mathematical statements to design recommendations, including solutions to specific practical problems.

The book begins with a Foreword that gives a historical perspective and reviews the bibliography on the optimal design of shock and vibration isolators. This review draws extensively from numerous Russian publications of 1960s through 1990s, which makes it especially interesting for the English-speaking audience.

Chapter 1 is the key to the book. It contains basic definitions and explanations of authors' approach to the optimal design of shock and vibration isolators. The central concept is that of limiting isolation capabilities, or limiting performance. It involves seeking an isolator characteristic among a wide class of functions depending on time. Under this definition, the resulting efficiency does not depend on the technical means used for isolation. It depends only on external disturbances, initial conditions and constraints.

The authors describe the Pontryagin's maximum principle as the most universal criterion for finding the solution of the optimal isolation problem, and outline the main steps necessary for its application. Multicriteria optimization techniques are illustrated by the optimization of instant shock isolation by a linear single-degree-of-freedom spring-and-dashpot system. Substantial attention is paid to the graphical techniques of finding the optimal control for a single-degree-of-freedom system, when the amplitude of the control is limited, whereas the excitation exceeds this limit in a certain time interval. Several example problems are solved for short rectangular pulses and half-sine disturbances.

Chapters 2 and 3 are devoted to the optimal protection of a single-degree-of-freedom system from an instantaneous shock. In Chapter 2, rectilinear motion is considered. Upon establishing that the limiting capabilities are represented by the constant control force, the authors concentrate on controls represented by a sum of a general non-linear stiffness and a general non-linear damping, in particular those described by power law characteristics. They identify several isolator characteristics that realize the limiting performance exactly. They note also that a traditional linear spring-and-dashpot isolator with optimal stiffness and damping coefficients provides the isolation quality that is only 4% below the limiting capabilities. Chapter 3 deals with a rotating object. The derivation is somewhat different due to the presence of centripetal acceleration. Although the limiting performance is achieved when the overload of the protected point is constant, the control force is not constant.

Chapters 4 and 5 deal with uncertainties of information about the system. In Chapter 4, the external disturbance is not given exactly but assumed to belong to a prescribed class of disturbances. Here, the central question is that of the "worst disturbance". It is shown that, for an integral constraint on the excitation of a single-degree-of-freedom system, the instantaneous impact represents the worst case if the class of isolator characteristics is limited by those including only dry friction, viscous linear friction and nonlinear elasticity. In that case the solution is drawn, naturally, from Chapter 2. For the case of two successive impacts, a bang-bang feedback control law is derived. The general case of multiple impacts is considered in Chapter 8 devoted to numerical methods.

Chapter 6 considers vibration isolation of the object attached to a harmonically oscillating foundation. The force transmitted to the foundation is minimized with restrictions on the relative displacement. Optimal values of damping coefficients are found for a linear damper and a dry friction damper.

Chapter 7 contains analytical solutions of optimal damping problems for multi-degree-of-freedom

Shock and Vibration 8 (2001) 367–368
ISSN 1070-9622 / $8.00

lumped-mass and continuum systems. The class of external disturbances is limited to square integrable functions, hence, only transient vibrations are considered. The optimization criterion is the integral of the total energy over the infinite time interval. The solutions are given for scalar controls (a force applied to one mass of a mass-spring chain or one point of an elastic rod).

Chapter 8 plays a central role in the book. It is devoted to computational methods that tackle much wider spectrum of real-life problems than the analytical solutions. The main technique here is the time-domain discretization. It reduces limiting performance investigation to a mathematical programming problem; moreover, in many important cases the problem is reducible to linear programming. The convergence of numerical algorithms is estimated by means of comparison with analytical solutions from previous chapters. Then the authors apply their techniques to four different problems related to design of various injury prevention systems. This Section will be extremely useful for design engineers. It provides both guidelines for applying the computational methods and insight into design tradeoffs and optimal solutions to typical shock isolation problems.

Chapter 9 discusses mathematical models of pneumatic springs and hydraulic dampers. After that, three specific isolators utilizing these elements, as well as dry friction, are considered, and their design parameters optimized to match the limiting performance provided by a constant resistance force. The examples include shock isolators for a railroad car coupler, an aircraft landing gear and the barrel of an artillery gun.

Constant resistance force is a universally adopted control strategy for designing commercial shock isolation. In Chapter 10, however, the authors question this strategy. A few examples of non-constant optimal control forces are considered here, in particular a preview control for a single-degree-of-freedom system under an instantaneous shock. The latter problem demonstrates an impressive eight-fold reduction of the peak relative displacement, compared to the case of the optimal constant-force non-preview control.

The authors confine their analysis of specific components of isolation systems to springs, dry or viscous friction elements, pneumatic cylinders and hydraulic dampers. The contents would benefit if other types of elements, such as viscoelastic elastomers and inertial masses, were included.

The terminology may be confusing at the first reading. The active control is defined as one depending on time explicitly. It is a convenient formal definition, which, however, differs from the widely adopted notion of an active control system as one containing sensor-actuator loops and using external source of energy. Furthermore, the authors apply the term "feedback" universally, whereas it is usually associated only with active systems. It takes some time to get used to the basic definitions, notation and problem statements, but the reader is rewarded with a deep and systematic understanding of basics underlying the diverse and complicated field of optimal shock and isolation problems.

The book is very carefully written. Unlike many other books on system dynamics for engineers, this text never omits mathematical proofs and details of formulations. It is mentioned in the Preface that a smaller print is used for auxiliary material such as certain proofs, which might be a good idea; nevertheless, the reviewer did not find this small print anywhere in the book. The sacramental phrase of a weary author, "it can be shown that . . ." is never found on these pages. At the end of each chapter, the authors give a helpful review of the main results, pointing out possible applications, generalizations and outstanding problems.

The book does an excellent job of bridging the gap between mathematical optimization and engineering practice.

The authors address their book to "mathematically oriented researchers and engineers". With mathematical methods penetrating the modern engineering practice, this is a large and ever-expanding group, and its members will undoubtedly find this book extremely helpful. The book is recommended for graduate students of theoretical mechanics and mechanical engineering. It can provide valuable material for inclusion in a short course on shock and vibration control. It should find its place in the libraries of research facilities, universities and technical colleges.

V.M. Ryaboy
Newport Corporation
Irvine, CA 92606
USA