Preface

This volume contains extended versions of the five plenary lectures given at the Euromech Colloquium 397 “Impact in Mechanical Systems”, at Grenoble, from June 30 until July 1–2, 1999, France. As the title indicates, it is devoted to the study of rigid multi-body mechanical systems subject to nonsmooth effects, such as impacts, Coulomb friction, constraints addition and deletion. Actually, this represents a large and important class of nonsmooth mechanical systems. Its study can be traced back to the ancient Greeks. The 17th and 18th centuries also witnessed a great deal of (scientific) excitement about shock dynamics. Prestigious names like Descartes, Newton, Poisson, Gauss, Huygens, Bernoulli, to name a few, have long been attached to the study of collisional effects between two rigid bodies. Later, scientists like Darboux, Routh, and Carnot, also contributed significantly to the field. The earliest studies on impact dynamics were essentially motivated by fundamental scientific questions in physics (what is the role of hardness in the rebound phenomenon, is springiness necessary for a rebound to occur, use in light models), as well as more practical goals (calculation of bullet trajectories).

Interest in such a class of dynamical systems today is certainly much more related to engineering, and in particular the development of simulation software for virtual prototyping, a topic of great importance in industry. However, it still possesses strong connections with physics: the study of granular matter, planetary rings, may benefit from using the models described in this book (let us also recall that so-called billiards, which are a particular class of impacting lossless mechanical systems, have motivated intense mathematical studies). In particular, the study of Newton’s cradle is closely related to what one needs to properly understand and predict phenomena such as clusterization and fluidization, which are well known in granular matter dynamics. In addition, numerical simulations are quite important in these fields. Furthermore, scientific communities like computer science (virtual reality), robotics, systems and control, applied mathematics and, evidently, applied mechanics find various fields of investigation in multi-body systems. As the reader will see throughout this book, nonsmooth mechanical systems with unilateral (or inequality) constraints represent a very interesting class of dynamical systems. They are not a simple extension of systems with bilateral constraints, or of systems with impulses. To express it in a language that has recently become fashionable in the computer science and systems and control communities, they constitute a class of hybrid dynamical systems; in other words, they merge continuous as well as discrete-event phenomena (roughly, their state space may be seen as the product of $\mathbf{R}^n$ with a finite set of symbols). Contrary to some widely held opinion, their dynamics is quite complex.

Many important problems associated with the dynamics of multi-body mechanical systems with unilateral constraints still remain open: mathematical problems (existence, uniqueness, continuous dependence on initial data, bifurcations, chaos), numerical analysis problems (how to discretize such a complex mixture of differential equations and algebraic conditions), mechanics (some phenomena, such as multiple impacts, with or without friction, still require much study on the modelling side), systems analysis (controllability, stabilizability). The five chapters in this book contain contributions related to mathematics, modelling and numerical simulations.

- **Mathematical Analysis** The first chapter, by M. Kunze (Mathematics Dept., Cologne University) and M.D.P. Monteiro-Marques (Mathematics Dept., Lisbon University), is devoted to presenting the so-called Moreau's sweeping process. This evolution problem, invented by Moreau in the 1960s, applies to quasistatics as well as to dynamics. It was first motivated by applications in fluid mechanics and later on in nonsmooth mechanical systems. The focus of this chapter is on mathematical analysis.
- **Numerical Analysis and Simulation** The second chapter, by M. Abadie (Schneider Electric Research Center, Grenoble), is dedicated to numerical simulation problems. It describes the work done at the company Schneider Electric to improve the virtual prototyping of electrical devices. It also contains an overview of the existing tools for simulation of nonsmooth mechanical systems. As with other analyses, our nonsmooth systems require very specific numerical tools and cannot be accomodated by classical software and algorithms. The algorithms presented in this chapter have been inspired by the discretization of the sweeping process as done by Moreau (see the first contribution), with appropriate modifications to comply with industrial needs (they are to be used directly by Schneider's engineers), whereas Moreau's scheme was primarily devoted to the simulation of granular matter.
- **Stability and Bifurcations** The third chapter by A. Ivanov (University of Moscow), deals with stability and bifurcation phenomena. It is a fact that systems with unilateral constraints possess specific sorts of bifurcations which are not encountered in smooth dynamics. They occur with grazing trajectories and have therefore been called grazing bifurcations. Also, the stability of trajectories requires new analytical tools.
- **Energetical Restitution Coefficient** The contribution of the fourth chapter by W.J. Stronge (Mechanical Engineering Dept., Cambridge University), focuses on collisions between two bodies using elasto-plastic models. It concentrates on the study of an energy coefficient of restitution. It also contains some developments on multiple impacts (the so-called Newton's cradle).
- **Multiple Impacts** The final chapter, by Y, Hurmuzlu and V. Ceanga (Mechanical Engineering Dept., Southern Methodist University), concentrates on multiple impacts without friction. It proposes a completely new way to attack the multiple impact problem, by using a new set of physical coefficients

(including the energetical coefficient presented in the previous chapter) to describe the shock phenomenon. Newton's cradle and the rocking block are used to develop the theoretical analysis. Experiments confirm the analysis.

In summary, this volume is an advanced introduction to the field of analysis, modelling and numerical simulation of rigid body mechanical systems with unilateral constraints. It will be worthwhile reading for anybody interested in this topic, be it at the mathematical, mechanical or numerical level. In fact, all these fields of investigation feed one another and it is almost compulsory to have a general view of the problems in the other fields to be able to propose sound solutions in a particular domain. The book contains some established (although not always very well known outside the nonsmooth dynamics community) results, as well as quite new ideas.

I would like to express warm thanks to my colleagues who kindly accepted to prepare a plenary talk at the Euromech 397, and, most importantly, who made the effort to write these chapters. They are gratefully acknowledged here. I would also like to recall that the Euromech Colloquium 397 was organized within the framework of a European INTAS project coordinated by Bill Stronge. This book rounds off this cooperation nicely.

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