Mechanics of non-holonomic systems

A New Class of control systems

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Preface to the English edition

The first equations of motion of nonholonomic mechanics not including the Lagrange multipliers have been reported at a scientific seminar in 1895 and published in 1897 by the world famous specialist in hydromechanics, academician of the Soviet Union Academy of Sciences Sergei Alekseevich Chaplygin (1869–1942). One of his favourite pupils, who worked under the direct supervision of S. A. Chaplygin since 1929 till 1941, was Professor Nikolai Nikolaevich Polyakhov (1906–1987). In 1952–1987 N. N. Polyakhov was the head of the mechanics department of the Faculty of Mathematics and Mechanics of Leningrad University and in charge of the chair of theoretical and applied mechanics, then since 1977 he headed the chair of hydromechanics. As well as his teacher, Nikolai Nikolaevich successfully studied not only problems of hydromechanics (he has created, in particular, the mathematical theory of a water propeller), but being at the head of the chair of theoretical and applied mechanics, he also turned to studying nonholonomic mechanics.

N. N. Polyakhov published his first works in this direction in 1970–1974. Since 1975 the investigations under the supervision of N. N. Polyakhov and with his personal participation had been regularly conducted. They were summed up in Chapters "Motion with constraints"and "Variational principles in mechanics"of the treatise for universities "Theoretical Mechanics"by N. N. Polyakhov, S. A. Zegzhda, and M. P. Yushkov, which was published in 1985 by the Leningrad University Press and reprinted in 2000 by the "Vysshaya Shkola"("Higher School") Publishing House.

After the decease of N. N. Polyakhov (January 27th 1987), the direction in nonholonomic mechanics, which he had established, began to be developed by his pupils: Professors of Saint Petersburg University S. A. Zegzhda and M. P. Yushkov, and Professor of Chechen State University, the head of the department of mathematics and theoretical physics of the Academy of Sciences of the Chechen Republic Sh. Kh. Soltakhanov, a graduate from Polyakhov's chair. Their collaborative work, to which they had devoted so many years, was completed in 2002 when the monograph "Equations of motion of nonholonomic systems and variational principles in mechanics"was published at Saint Petersburg University. In 2005 the Moscow Publishing House "Nauka"("Science") published the second revised and improved edition of this book "Equations of motion of nonholonomic systems and variational principles in mechanics. A new class of control problems". This very book, extended for the English edition, is offered to readers. This book is dedicated to the 100th anniversary of the birth of our teacher Professor N. N. Polyakhov.

The prominent specialist in nonholonomic mechanics, Professor J. G. Papastavridis (Professor of Georgia Institute of Technology, USA) has undertaken the work of Editor-in-Chief while editing the book in English. It was translated by Dr in phys.-math. sciences E. A. Gurmuzova. Gratefull acknowledgement is made by the authors to all those who helped in preparation of this book — E. L. Belkind, D. N. Gavrilov, D. V. Lutsiv, A. E. Mel'nikov, A. A. Nezderov, E. M. Nosova, G. A. Sinilshchikova, K. K. Tverev, S. V. Zaykov.

The authors are deeply indebted to the "Springer"Publishing House, and the publisher of the series "Foundations of Engineering Mechanics"Professor V. Babitsky and the editor Dr Ch. Baumann, for their valuable advice that contributed greatly to improving this book. It is due to their recommendations that the contents of the book has been considerably extended. The authors are also grateful to Ms C. Wolf and Ms V. Jessie who contributed much to preparing the book for the press.

While writing the book, the authors gave much attention to the role of the Lagrange multipliers in analytical mechanics. Holonomic and classical nonholonomic mechanics are presented in the framework of one approach, in this case the properties of constrained motion which are typical of one particle (mass point) can be observed in any mechanical systems with the finite number of degrees of freedom. Such an approach makes it possible to construct also mechanics for the motion of systems with any-order constraints, which are considered as programming ones. Reaction forces of these constraints are interpreted as control forces that provide the motion of system under realization of the program given as an additional system of differential equations, the order of which is higher than two. Thus, a new class of control problems is introduced. The offered theory is illustrated through solving two examples of motion of real mechanical systems with three-order constraints imposed on their motion.

In the monograph much attention is given to studying practical problems. Along with solving a number of classical problems (for instance, problems dealing with investigation of a car motion with possible slipping of driving wheels and sideslip), a number of new methods for solving important practical problems is proposed in the book. The reader is asked to pay special attention to the two of them (see Chapter VI).

The first method makes it possible to find natural frequencies and natural modes of vibration of an elastic body system in terms of the known natural frequencies and natural modes of the system's separate elastic bodies (its parts). Due to the dynamical consideration of the finite number of natural modes and quasistatical consideration of the higher ones of the system's elements, the lower frequencies can be determined with a high accuracy from an algebraic equation.

The second method is concerned with the problems of damping the vibration of mechanical systems. Instead of the commonly used method that is based on the minimization of the functional of control force squared, it is offered to apply the generalized Gauss principle stated in the monograph for

solving similar problems. As a result, the control force can be constructed as a polynomial in time. During the given time this force transfers smoothly a system from one state to another, in particular, to the state of rest.

Especially important for the authours is the fact that their work is published in the English language, which plays today in scientific communication the same role as Latin in the Middle Ages. In this regard this monograph can be useful for English scientists. It will help them to get acquainted with a rather great number of works by Russian scientists.

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