Vibratory and Controlled Synchronization Engineering

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Introduction to the First Author

Wen Bangchun, was born in Hangzhou, Zhejiang Province, China, graduated as a postgraduate from Department of Mechanical Engineering at Northeast Technology of University(Now it is Northeastern University) in 1957. Mr. Wen now is professor in College of Mechanical Engineering and Automation, honorary director of Institute of Mechanical Design and Theory in Northeastern University, member of Chinese Committee of IFToMM, member of Technology Committee of International Rotor Dynamics Committee, member of Guidance Committee for Asia-Pacific Vibration Committee, honorary chairman of Chinese Society of Vibration Engineering, honorary director of "Vibration, Impact and Noise" National Key Lab in Shanghai Jiaotong University. Professor Wen was member of the 6th, 7th, 8th and 9th Chinese People's Political Consultative Conference, a review member of Mechanical Engineering Course of the 2nd, 3rd and 4th Chinese State Consul Degree Committee, Chairman of Chinese Society of Vibration Engineering and chief editor of *Journal of Vibration Engineering*. Professor Wen was and is the advisory professor and honorary professor for more than 20 Universities. He received the honor of National Youth and Mid-aged Expert in 1984 and he was elected to be a member of Chinese Academy of Science.

Professor Wen systematically studied and developed the new course of "Vibration Utilization Engineering" combined with vibration theory and machinery. In addition he also studied some problems of rotor dynamics, nonlinear vibration and applications of mechanical engineering, vibration diagnostics of the machine fault, mechanical-electronic integration and the machinery engineering theories. He has written more than 700 papers of which 250 papers are in SCI, EI and ISTP index systems. He also wrote some books and edited more than 10 collected papers.

Professor Wen advised more than 150 graduates in which 89 students

obtained their master degrees, and 64 obtained doctor degrees. He advised 10 post-doctors, a Russia and a Kazakhstan visiting scholar.

Professor Wen was invited to give lectures to Japan, Germany, Australia, etc., participated international conferences in US, UK, Japan, Australia, Italy, Korea, Bulgaria, Hungary, Singapore, Malaysia, Finland, For USSR, Spain, etc. and presented more than 50 papers and invited to make keynote speeches. He has organized 4 international conferences and was chief-editor for 4 international conference proceedings.

Professor Wen accomplished many national key research projects, including key projects from National Fund of Natural Science, 973 and 863 projects, he received 2 international awards, 4 National Invention and Science and Technology Progress awards, more than 10 Province or Department awards, and he filed 10 National patents. Some of the projects have reached international levels.

This book is one of the important research results in his and his team work for more than 30 years.

Preface

A synchronous phenomenon is a form of movement naturally existing in nature as well as in human society and production. Most synchronous phenomena are naturally formed during the evolution process of the natural world and the human society. However, in engineering and technology, it is often created artificially to satisfy people's needs. In most cases, the synchronous phenomena are beneficial to human beings, but are harmful in other cases. For example, synchronous satellites in space orbit in synchronization about the earth. Another example of the synchronization phenomena is in radiobroadcast, one of the most common ways to transmit information in human lives. In order to receive the expected sounds from radio stations, the receiving frequency of the radios must match the sending frequency from the radio stations, which is so-called sending-receiving synchronization. But in other circumstances, the synchronization phenomena may be unwanted as they may be hazardous and harmful. For example, soldiers are forbidden from marching synchronously in a group on a wire bridge, because the resonant forces produced by the synchronized running may cause a disaster.

The synchronous phenomena and their issues can be found anywhere in the natural world and fields of engineering and technology.

In the natural world, congeneric species of flowers usually bloom at the same time; sunflowers always change their orientation with position changes of the sun; tides always periodically rise and fall with position changes of the moon; fireflies always synchronously flash at the same frequency in summer nights; and dolphins can complete their complex and exciting synchronous performances by means of their communication. In the universe, a huge number of stars are synchronously running in the Galaxy.

In engineering and technology fields, a variety of synchronous phenomena and problems are prevalent. For example, to obtain accurate

time and measurement, clocks and scales are required to be calibrated with the standard ones. In mechanical engineering, two or more components of many machines, such as rotating shafts, linkage mechanisms, and the pistons of cylinders etc., are expected to have the same velocity, displacement, acceleration, phase or force. That is, the machines are expected to operate in a synchronous state to meet the requirement of some specific process. For example, dual- or multi-motor driving vibrating feeders, vibrating conveyors, vibrating screens, vibrating dryers, vibrating coolers, vibrating pile hammers, synchronous rolling mills, stretching straighteners, two-reel driving belt conveyors, roller crushers, paper mills, briquette makers, bridge and gantry cranes, hydraulic lifters, flying shears, gates of dams and docks, etc., have a requirement of synchronization of two or more components. Another example is ship lift in Three Gorges. Due to a need of immense power, a multi-motor synchronous drive is required which makes the lifting wires have an approximate same velocity and an even distribution of load. In engineering, there are too many such examples to list in this book.

In order to achieve synchronization of multiple objects, some constraints or connections must be made among them. The most common ones are the use of mechanical, dynamic and control methods.

The methods for the synchronization of mechanical systems are constantly developed and improved with the development of science and technology, and the developing process of synchronization of mechanical systems can be divided into the following three stages.

The first generation of synchronization: use of the rigid (gears) or the flexible (chain or belt) mechanical transmissions.

The second generation of synchronization: vibratory synchronization for vibrating machines with two exciters, or electric axe for general purpose machines.

The third generation of synchronization: controlled synchronization or the combination of controlled synchronization with vibratory synchronization.

In order to ensure that these kinds of machinery work safely and reliably, it is not only an important academic value but also a great practical

significance to study the theories of synchronization to reveal the principles of synchronization.

In the 1960s, Dr. Blehman (Russian) first proposed the synchronization theory of the vibrating machines with two or multiple exciters. The use of this theory resulted in an extreme simplification of the synchronous machines, which made the maintenance easy and convenient, and greatly increased the reliability of the machines. Thus the synchronization technology has been widely applied in engineering. So far, millions of vibrating machines based on the principles of the vibratory synchronization are working in industries, and have created great economic and social benefits.

This book is a summary of authors' researches on the synchronization theories proposed for the solutions of engineering problems. In about 30 years, the authors have developed the theories of vibratory synchronization, and proposed the synchronization theories of plane (2D) and spatial (3D) motion self synchronous vibrating machines, centroid rotation vibrating machines, near-resonant self synchronous vibrating machines, and the theories and methods of vibratory synchronization transmission, etc. The applications of the theories and the methods in engineering have brought remarkable economic and social benefits.

Since the 1980s, the rapid development of control theories has made the controlled synchronization possible from a technical point of view, and the application of the control theories has resulted in more satisfactory accuracy and better stability. By using the advanced technology, the machines can be well controlled to operate in an optimum state, which has yielded increasing efficiency and process indicators. The mechanical systems with controlled synchronization also have simpler structures compared to the conventional synchronous systems having complex mechanical transmissions. Therefore, they are easier to maintain and have higher reliability which has brought great economic and social benefits.

So far, we have seldom seen any special books in both domestic and international literatures which fully and systemically describe the vibratory synchronization and controlled synchronization in engineering and

technology. Therefore, in this book, the authors focus on the results of their long time theoretical and experimental studies. In addition, this book also incorporates the latest results of domestic and international researches in the field.

It should be noted that most of the contents of this book are taken from the two projects completed by the authors, with the support of the Natural Science Found Committee of China—"Study on Theory and Its Application of Controlled Synchronization of Mechanical Systems" and "Study on Theory and Its Application of General Synchronization and Intelligent Fixed Speed Ratio Drive Control of Multi-motor Mechanical Systems". Hereby, the authors would like to express their thanks to the support of the committee.

There are 9 chapters in this book. The first five chapters cover the vibratory synchronization and the vibratory synchronous transmission of the vibrating machines of plane (2D) or spatial (3D) motion, and the controlled synchronization of dual- or multi-motor mechanical systems is discussed in Chapters 6 and 7. Chapters 8 and 9 focus on the combined synchronization control and the fixed speed ratio control of dual- or multi-motor mechanical systems, respectively. This book was prepared and written by Wen Bangchun, Fan Jian, Zhao Chunyu and Xiong Wanli.

I would like to thank Professor Guan Lizhang and Professor Zhang Tianxia for the valuable information and materials provided for the preparation of this book, and I also want to thank all of our friends and colleagues for their help as I worked on the projects and the preparation of this book. This book may not investigate vibratory synchronization and controlled synchronization in mechanical systems entirely. We sincerely welcome readers' criticisms and comments.

Wen Bangchun

Contents

Chapter 1 Development of the Theory and Technology of Vibratory Synchronization and Controlled Synchronization

1.1 Synchronization phenomena and problems in the natural world and engineering

Synchronization is a movement form which objectively exists in the natural world and the human society, as well as the fields of engineering and technology. So-called synchronization, is that two or more things or objects exhibit the same or similar movement form or physical form and state, such as the same speed, the same phase, and the same or similar orbit, etc. These required synchronization forms or physical states are called synchronous parameters. In general, these motion forms and states, in addition to the displacement, velocity, acceleration, phase and orbit, also include the force and various physical quantities describing the physical motion forms and states of an object. In a mechanical system, that two or more components, such as rotational shafts, mechanisms, links, cylinders and pistons, even machines, synchronously operate at the same (or a fixed ratio) displacement, velocity, acceleration and phase, or under the same loading condition is called synchronization. In a synchronous process, the parameters of the two objects may not be exactly the same. The difference or error between them can be used to represent the grade of the synchronization.

In the natural world, the human society, or the fields of engineering and technology, the synchronous phenomena or synchronous problems can be found everywhere. There are synchronous phenomena or synchronous problems in every field of science and technology that people involve, such as in the fields of the cosmography, the chemistry, the electromagnetics,

the medicine, the bionomics, the life sciences, the economics, the electrical technology, the radio technology, the electronic technology, the mechanical engineering, etc. The synchronous phenomenon or synchronous problem universally exists.

In the universal space, all the stars in the Galaxy have always been repeatedly maintaining a stable synchronous operation. In the natural world, the cells multiply synchronously, the plants grow synchronously, the flowers bloom synchronously, the insects call synchronously, the fireflies flash synchronously, and the birds fly and reside synchronously. In the human society, family genes are synchronous and similar, the economic status in different regions develops synchronously and similarly, when a band or a chorus acts collectively, various instruments are played synchronously and co-operatively, the song is sung synchronously by the singers, and the dancers dance synchronously. In the fields of science and technology, the synchronization of clocks, and the synchronization of various measure instruments and devices are the examples of synchronization. In order for a radio to receive the signals from radio stations, the receiving frequency must be approximately equal to the sending frequency. In lots of mechanical equipment, two or more components are usually required to operate synchronously, such as the vibrating feeder with two exciters, the vibrating conveyor, the vibrating screen, the vibrating dryer, the vibrating cooler, the vibrating pile hammer, the synchronous rolling mill, the stretching straightener, the two barrels driven belt conveyor, the roller crusher, the paper machine, the cool, the bridge or gantry cranes, the coal briquette machine, the hydraulic lifting machine, the flying shear, the spindles of textile machine, as well as the gates of the dam and dock. The ship lifting machine used in "Three Gorges", due to the use of multi-motor drives, is required for the every cable driven by the motors to have the approximate velocity and load, that is, a synchronous operation.

From a broader perspective, a simulation process, even a learning process, is itself pursuit of the synchronization and similarity. For example, a robot imitates the human movement, or follows a motion rule designed in advance, this is particular synchronization.