Bangchun Wen · XianLi Huang ·
Yinong Li · Yimin Zhang

Vibration Utilization Engineering

華中科技大學出版社
Huazhong University of Science and Technology Press

Springer

Vibration Utilization Engineering

Bangchun Wen · XianLi Huang · Yinong Li ·
Yimin Zhang

Vibration Utilization Engineering

華中科技大學出版社
Huazhong University of Science and Technology Press

Springer

Bangchun Wen
Department of Mechanical Engineering and Automation
Northeastern University
Shenyang, Liaoning, China

Yinong Li
College of Mechanical and Vehicle Engineering
Chongqing University
Chong Qing, China

XianLi Huang
Technical Consultance
Freelance
Liaocheng, Shandong, China

Yimin Zhang
Shenyang University of Chemical Technology
Shenyang, Liaoning, China

Funded by National Natural Science Foundation of China (59475005, 50075015, 59075175, 59875010)

ISBN 978-981-19-0671-8 ISBN 978-981-19-0672-5 (eBook)
https://doi.org/10.1007/978-981-19-0672-5

Jointly published with Huazhong University of Science and Technology Press, Wuhan, China
The print edition is not for sale in China (Mainland). Customers from China (Mainland) please order the print book from: Huazhong University of Science and Technology Press.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Vibration, or oscillation, is a periodic movement in time of a system around a certain equilibrium position. The system consists of at least an element for storing kinetic energy and one for storing potential energy. The vibration is a process of energy-type exchanges between the kinetic and potential energies. The equilibrium position is the state in which the potential energy becomes zero. The periodicity of the movement is described in frequency which is the measurement of the numbers of times the repeated events that occurred in a unit time. Vibration is an omnipresent type of dynamic behavior of a system and exists in many forms, such as sound and music.

Human beings first recognized the vibration phenomenon by entertaining themselves with percussion, string, and plate music instruments in ancient times. Just like the time when the lever principle was discovered is much later than that of its real utilization in human history, the time when the vibration and acoustics theory on the principles of the music instruments were discovered is much later than that of the music instruments were made and played. The earliest music instrument unearthed in Henan Province, China, is a bone flute, which can be traced back about 6000–5000 years B.C., while the earliest string vibration frequency and music acoustic theory for a string instrument ever written and published in Chinese history is around 700 B.C. in "Guanzi" by Guan Zhong (723–645 B.C.). In his music-scale algorithm, if the length of the basic string for the major tone is 1, the string lengths of the next scales are either added 1/3 (4/3) of the basic length or subtracted 1/3 (or 2/3), other music scales are determined by this 1/3 length rule, and he obtained five tones by this algorithm: C, D, E, G, A. It's amazing that more than 100 years later the Greek Philosopher and Mathematician Pythagoras (570–504 B.C.) discovered independently the very similar theory for seven tones: The Pythagorean scale.

Human beings first learned the vibration and acoustics of the plates and shells also from music instrument manufacturers. "Kaogongji" or "Artificer's Record" 500 B.C. in Chinese history, recorded the Bian-Qing (sound bian-ching). It is a set of percussion, made of high-quality stones such as jade, with several fixed music scales. The "Kaogongji" specifically described how to adjust the percussion music scale: "if music scale is higher, filing the surfaces of the plate, if the scale is lower, then filing the edges of the plate". These technological processes, even though not giving exactly the

quantitative relation between the natural frequencies of the plate and its geometrical parameters, are indeed in accordance qualitatively with the contemporary vibration and acoustic principles of the plate and shells: filing the surfaces of the plate makes the plate thinner and natural frequencies will be decreased while filing the edges of the plate makes the plate relatively thicker thus the natural frequencies will be increased.

One of the most important dynamic properties for the vibrations of a system is the inherit frequency or natural frequency. The vibrating movements of a system occur by external forces or internal self-excitement. When the frequencies of the excitation are the same or near the system's natural frequencies, the responses of the systems will become larger and larger, which is called the resonance. The resonance has a variety of applications, such as radio, television, and music. The large-magnitude vibrations, such as large magnitude earthquakes, tsunamis, could bring harmful, devastative, and even catastrophic damages to properties and human lives. People tried to predict the earthquake by vibrating devices. In 132 A.D. Zhang Heng (78–139 A.D.), a Chinese mathematician, an astronomer, and a geographer, invented the vibration utilization device: Seismographer. The shape of the device looks like a goblet. Eight (8) exquisitely casting dragons, upside down, attached to the body of the device. The eight dragons are mounted in the North, South, East, West, Northeast, Southeast, Northwest, and Southwest directions, respectively, representing the earthquake directions. There is a ball in each dragon's month. There is a vivid toad, mounted separately to the body, under each dragon. It is said that when an earthquake occurs the dragon in the earthquake direction will release its ball in its mouth into the toad mouth as a prediction indication. The exact mechanism inside was not well documented. It was recorded in history books that this device had successfully predicted an earthquake about 600 miles away in 138 A.D. just 1 year before he died.

In modern days, tens of thousands of types of vibrating machines and instruments have been successfully used to accomplish a variety of technological procedures in the fields of mining, metallurgy, coal mine, petro-chemistry industry, machine, electricity, hydraulics and civil engineering, construction, railway, highway communication, light industry, food and grain processing, biological industry, information technology, and process of human everyday life. The technologies involved in this science branch are so closely associated to agricultural and industrial production that it can create great economical and social benefits, and can provide great convenience and excellent service for people's life. It becomes an inevitable means and a necessary mechanism for human production activities and life processes. A study of "Vibration Utilization Engineering" as a new branch of science has been gradually formed and developed in the latter part of the twentieth century to cope with the increasing demands of the vibration utilization.

The literature on vibration utilization is scattered over all the magazines, books, journals, and conference proceedings in different academic fields and different science branches. It would be difficult to look into and collect the information and references on different vibrating machines. It would be informative and convenient to have an encyclopedia type of a book to cover as many types of vibrating machines and as many aspects of vibration utilization as possible and provide multi-sources

and cross-references for scientists and engineers to use. This is part of our intention in writing this book. The authors attempt to summarize the scientific research works on the vibration utilization over more than 30 years. The book also includes the following original and creative results led by the first author and Professor Bangchun Wen and his team colleagues:

1. The authors constructed a theoretical framework for "Vibration Utilization Engineering", this terminology is first both in domestic and international areas.
2. In the technological theory and technology creativities, the authors introduced the creative results obtained on technological theories and practical applications in the Vibration Utilization Engineering such as Probability Iso-Thickness Screening theory; material sliding and throwing theory on different surfaces; and screening process theory and their applications in the vibration machine processes.
3. In mechanism creativities, the authors proposed a variety of new vibrating mechanisms, such as exciter-eccentric type of self-synchronically vibrating mechanism, special forms of non-linear inertial resonant type of vibrating mechanism, etc., patent approved.
4. In the non-linear dynamic theory creativities, the authors summarized the systematic studies and experiments conducted on vibration and wave utilization technology and equipment working theories and derived theory basis on many branches of the Vibration Utilization Engineering, such as vibration synchronization and application of the controlled synchronization theory, application of the non-linear vibration, etc. For example, the dynamic theory of a variety of vibrating machines and equipments, the equivalent mass and damping of vibrating machine systems, the theory and computing methods of the second vibration isolation of the vibrating machines and equipments, the vibrating synchronization theory and methods on duel- or multi-motor-driven vibrating machines, dynamic analysis, and dynamics parameter computation methods on non-linear vibrating machines, the dynamic design methods on vibrating machines and their main components, many of them are first published in this book.
5. In the design theory and method creativities, the authors proposed the systematic vibrating machine dynamic design theory and method, especially those for the non-linear vibrating machines and the comprehensive design methods which contain the dynamic optimization, intelligent optimization and visualization.
6. In the engineering applications, the authors have applied their theoretical results to engineering for over 30 years. For example, the inertia-resonance-probability screens, new mechanism type of vibrating cooling machines and new mechanism type of vibrating crushers, etc. These machines are rewarded by the National Invention, National Technology Progress, etc.

This book contains seven chapters. Chapter 1 introduces the formation and development of the Vibration Utilization Engineering; Chap. 2 devotes to some of the important research results in the vibration and wave-energy utilization in some technological processes; Chap. 3 describes the theories on the technological process

of the vibration utilization technology and equipments; Chaps. 4 and 5 discuss the vibration utilizations of the linear, pseudo-linear, and non-linear systems; Chap. 6 presents the utilization of the wave and wave-energy; and Chap. 7 briefly illustrates the vibration phenomena and utilizations in the Natures and human societies.

The authors include Bangchun Wen, XianLi Huang, Yinong Li, and Yiming Zhang. During the editing it absorbed the research results by the team members: they are Profs. Lizhang Guan, Guozhong Zhang, Liyi Ren, Shengqing Ji, Shuying Liu, Chengxiu Wen, Zhishan Duan, Jie Liu, Tianxia Zhang, Xun He, Haiquan Zeng, Peimin Xu, Yannian Rei, Shirong Yan, Huiqun Yuan, Qingkai Han; Associate Professors: Jian Fan, Jingyang Qi, Chunyun Zhao, Fenglan Wang, Suying Shu, Hongguang Li, Wali Xiong, Shide Peng; Senior Engineers: Xiangyang Lin, Mingfei Luo, Yongxi Liu, Zhaomin Gong, Hong Zhang, Tianning Xu, Qinghua Kong, Huajun Wang, and Naiqing Ma; Doctors: He Li, Hongliang Yao, Zihe Liu, Haiyan Wei. We also received help from Academicians: Wenhu Huang, Shuzi Yang, Jinji Gao, and Professors: Yushu Chen, Zhaochang Zheng, Haiyan Hu, and Dianzhong Wang. Doctoral Students Hong Chen, Xiaowei Zhang, Xiaopeng Li, Xueping Song, Li Wang, Tao Yu, Wei Sun, Hui Ma, and Juequan Mao. Thanks also go to Electronics and Machine Institute of Northeastern University, The Group of Xuzhuo Engineering Machines, the Capital Iron and Steel Corp, Luoyang Mine Machine Design and Research Institute, Anshan Mine Machine Limited, Henan Weimeng Vibrating Machine Limited, Chaoyang Vibrating Machine Factory, Haian Vibrating Machine Factory, and Zhongxiang Machine and Electrics Corp for their assistance.

It is noted that some of the research results in this book are coming out of the projects funded by the National Nature Science Foundation (Project # 59475005, 50075015, 59075175, and 59875010); Two Doctoral Student Fund Projects, and other scientific and research projects.

Shenyang, China — Bangchun Wen
Liaocheng, China — XianLi Huang
Chong Qing, China — Yinong Li
Shenyang, China — Yimin Zhang
September 2006

Introduction to the First Author

Bangchun Wen, born in Hangzhou city, Zhejiang Province, China, graduated from the Department of Mechanical Engineering at Northeast Technology of Institute (now it is Northeastern University) in 1957. He now is Professor in the College of Mechanical Engineering and Automation, Honorary Director of the Institute of Mechanical-Electronic Engineering, China Representative 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 Noise National Key Lab in Shanghai Jiaotong University. He was a member of the 6th–9th Chinese People's Political Consultative Conference, a member of the 2nd–4th Mechanical Engineering Branch of the Chinese State Consul Degree Committee, General Secretary of The Chinese Society of Vibration Engineering, and Chief Editor of "Journal of Vibration Engineering". He 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 the Academician of the Chinese Academy of Science.

He systematically studied and developed the new branch of "Vibration Utilization Engineering" combined with vibration theory and machinery. In addition, he also studied rotor dynamics, non-linear vibration, and applications of mechanical engineering, vibration diagnostics of the machine fault, mechanical-electronic integration, and some problems of the machinery engineering theories. He published more than 700 papers of which 150 papers are in SCI, EI, and ISTP index systems. He also wrote some books and edited more than ten collected papers.

He advised more than 100 graduates in which 61 students obtained their master's degree and 43 doctoral degrees. He advised five postdoctors, a Russian and a Kazakhstan visiting scholars.

He was invited to give lectures to Japan, Germany, Australia, etc., participated in international conferences in the US, the UK, Japan, Australia, Italy, Korea, Bulgaria, Hungary, Singapore, Malaysia, Finland, For USSR, Spain, etc., and published more than 50 papers and invited to make keynote speeches. He organized four international conferences and was the Chief Editor for four international conference proceedings.

He accomplished many national key research projects, including key projects from National Fund of Natural Science, 973, 863 projects, he received two international awards, 3 National Invention and Science and Technology Progress awards, more than 10 Province, Department, and he filed 8 National patents. Some of the projects have reached international levels.

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

Contents

Chapter 1
Formation and Development of Vibration Utilization Engineering

1.1 Introduction

Utilization of vibration and wave is a type of the most valued applicable technology developed during the latter part of the twentieth century and still in rapid development state now. Since the technology is closely associated with industrial and agricultural production, can create huge social and economic benefits for our society and provide excellent service for human beings, it becomes a necessary mechanism in human production and life. The scientists in the world put a lot of efforts to study the technology in this field, the authors and their teams spent more than 30 years in the investigation and research in this field and achieved a series of research results and hence brought about the formation and development of the branch.

One of the indications for the rapid development of the technology is the variety of the vibrating devices, equipment and machines and the diversity in the fields of their application and utilization. In the industries, such as Mining, Metallurgy, Petrochemistry, Mechanical Engineering, Electricity, Hydraulics, Civil Engineering, Construction, Building Material, Railway, Highway Transportation, Light Industry, Food Processing and Farmland Cultivation, tens of thousands of vibrating devices, equipment and machines have been used to accomplish many technological processes such as material feeding, conveyance, screening, material distribution, drying, cooling, dewatering, selecting, crashing, grinding, shaping, burnishing, shakeout, ramming, rolling, paving, drilling, loading, pile sinking, pile pulling, extracting oil, cleaning, bundling, aging, cutting, checking pile, detecting, exploring, testing, diagnosing etc. These machines include the vibrating feeder, vibrating conveyor, vibrating shaping, vibrating screen, vibrating centrifugal dehydrator, vibrating drier, vibrating cooler, vibrating freezer, vibrating breaker, vibrating polisher, vibrating grinding mill, vibrating burnisher, vibrating rollers, vibrating paver, vibration earthener, vibration sinking piling machine and a variety type of shakers and shockers, etc.

Utilization technology of the vibration and wave is based in a wide range of vibration principles. In addition to linear and nonlinear vibration theories, the linear and non-linear stress wave are used for detection and geology exploration. In petroleum

B. Wen et al., *Vibration Utilization Engineering*,
https://doi.org/10.1007/978-981-19-0672-5_1

exploitation, the elastic waves generated by vibrations are used to increase the oil output. In the Ocean Engineering, the energy of the tidal waves can be used to generate electricity. In the Medical Equipment, the supersonic wave is used to diagnose and cure diseases. In the other in medical settings the color ultrasound, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are the medical applications of the vibrations. The application of the light-fiber and laser is the typical application examples of the vibrations.

In the perspective of the electronic and communications, the oscillating circuits in televisions and radios, door bells, telephone mechanical and electronic watches, clocks, light-fiber communication technology, recorder, just to name a few of them, they all work effectively due to the vibration principles.

In retrospect of the past history, we can see that the utilization of vibration and waves has been made some new reforms in some scientific fields and even brought about new revolutions in field and industries. For example, the study and research on self-synchronization theory have successfully pushed the appropriate inertial vibrating machines and mechanical industries to significant changes. The successful introduction of the controllable electric–magnetic feeders in some industrial enterprises has improved their production automations. The utilization of the Vibrating Roller and Spreaders in road constructions has improved the highway construction quality and enlarges the highway usage life; the quartz oscillators have made a revolution in the Watch and Bell Industries; the successful creation of the supersonic motors makes the compact, small power and lower rotation motors a reality; the color ultrasound and CT machines make the medical detection and diagnostics technology a revolution; the successful study of light-fiber promotes a revolution in the communication technology. We can see from above examples that the utilization technology of the vibration and waves has very important effects on human's life and production activities.

Generally speaking, in the social and economic life, the growth and attenuation of the human population, the periodicity of the insect calamity, the ups and downs of the stock markets, and increase and decrease of the growth speeds in social economy development process can be all classified, in some sense, as different forms of vibrations and oscillations. In the Nature and the Universe there exist vibrations everywhere: the Moon's phase, the tide's in and out, the tree's annual rings, etc. It is no doubt that studying on the vibration and wave phenomena, finding out the intrinsic patterns, and making use of the patterns effectively can produce the social and economic benefits and bring the benefits to mankind.

The vibration and waves can be categorized roughly as two types: Linear and Non-linear systems of vibrations, waves (sound wave, light wave) and electric–magnetic oscillations. We can classify the utilization of vibration and wave into the linear and non-linear vibration utilization, wave motion and energy utilization and the electric–magnetic oscillation utilization in engineering, the phenomena, patterns and utilization of the vibrations in Nature and human social society (see Fig. 1.1). The vibration utilization, from very low frequency (tidal waves) to very high frequency (ultrasound), can all be effectively utilized (see Fig. 1.2).

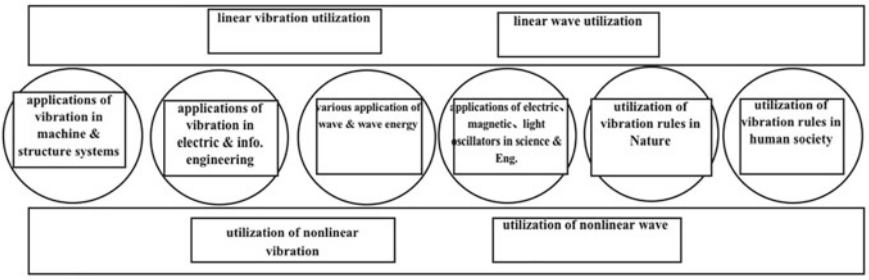

Fig. 1.1 Linear and nonlinear vibration utilization fields

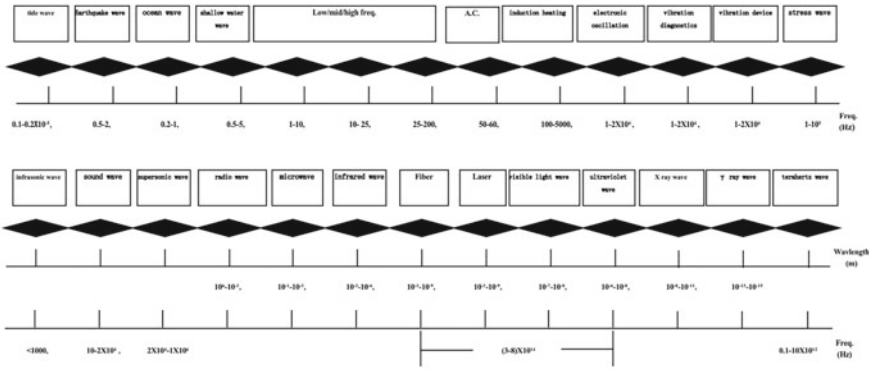

Fig. 1.2 Vibration and wave distribution by frequency or wavelength. *Note* Waves are arranged from left to right not totally by its magnitude or wavelength

1.2 Vibrating Machines and Instruments and Application of Its Related Technology and Development

Linear and nonlinear vibration utilization technology are accomplished via vibration mechanics or vibrating instruments which could generate the vibration. The vibrating machines or vibration instruments as a special equipment or device have been widely used in industry and agriculture productions. Table 1.1 shows some major usages for vibrating machines and instrument.

New vibration utilization technologies emerged as science and technology are developing. Here are some examples:

(1) Vibrating Drying Technology

Drying is a complex technological process in industry production. The technology is newly developed in recent years in vibration utilization engineering. The Vibrating Vulcanizing Machine is developed on the basis of a general Vulcanizing Machine.

Table 1.1 Vibration machines and equipment categorized by their usages

Type	Usage	Machines or device names
Conveyer/Feeder types	Conveyance, feeder, part arrangement,	A variety of bulkhead vibrators, EM vibration feeder, inertial resonance feeder, vibration hopper conveyance: EM vibration conveyor, inertial resonance conveyor, elastic connecting rod type of vibration conveyor
Screen/Dry types	Screen, selection, dry, cooling, hydro-extraction	EM vibration screen, inertial vibration screen, resonance screen, rotating vibration screen, probability screen, vibration dryer, vibration centrifugal hydro-extractor, hydro-extraction screen, vibration ore selector, table
Crush/cleaning type	Powder polish, crush, sand washing, ice-crushing, cleaning, dust-removing	Vibration polisher, coarse crusher, inertial vibration crusher, vibration sand washer, vibration loader, vibration shovel, pneumatic shovel, rock drill
Shaping/compacting type	Shaping, solid, rolling	Vibration shaper, vibration densifier
Ramming/pile drive type	Rolling of road, spread, pile driving, ramming, excavating, loading, rock drilling	Vibration roller, oscillation roller, spreader, vibration pile driver, attaching type of vibrator, insertion type of vibrator, rammer
Test/Display type	Excitation, test, display, etc.	A variety of exciters, vibration tables, vibration simulator, dynamic balance test machines, fatigue test machines, mechanical type of vibration measuring device, a variety of vibration motors
Monitoring/Measuring types	Monitoring, diagnostics	A variety of monitoring and diagnostic device and equipment
Others	Ageing, cutting, massaging, bundling, well cementation	A variety of exciters

Table 1.2 Utilization of nonlinear vibration characteristics

Sequence number	1	2	3	4	5	6	7	8	9	10	11
Types of nonlinear vibration characteristics	Utilization of piece-wise inertial force system	Utilization of smooth nonlinear system	Utilization of piecewise-linear nonlinear system	Utilization of nonlinear hysteresis system	Utilization of self-excitation vibration system	Utilization of nonlinear vibration with impact	Utilization of slow-changing parameter system	Utilization of frequency entrainment principle	Utilization of nonlinear elastic system	Utilization of bifurcations	Utilization of Chaos
Application examples	Vibration conveyers, vibration centrifuges	Friction pendulum, flode pendulum, electric–magnetic feeder	Vibration feeder, vibration centrifugal hydro extractor, inertial resonance screen	Vibration roller, spreader, pile driver	Pneumatic or hydraulic Rock drill, pneumatic puncher, oscillator	Rammer, inertial vibration puncher, vibration shaper	Working process of many vibration machines	A variety of self-synchronous vibration machines	Utilization of longitudinal and transverse elastic vibration systems	Frog-rammer applications of hyperbolic movement state	Chaos encryption system, chaos mixer

(2) Vibrating Crusher

Crushing of materials is a widely used technological process in the mining industry. Most of the ore materials need to be crushed and grinded. The breaking means of a traditional crusher has its limitations. For example, when the materials to be broken have compressive strength of more than 2×10^8 Pa the breaking process will consume large energy, the ore and materials are difficult to break and crush or the materials are over-broken. The machines are very complex. The development of vibrating breaking and crushing technology then overcomes these shortcomings. Cylindrical Inertial Vibrating Crusher is used to break the ore and other mineral materials by the centrifugal forces generated by an eccentric mass and the extruding and impact forces break the materials. The crushing rate by the vibrating crusher is much larger than that of traditional cylindrical inertial crusher and can be adjusted in a large range. It has bright future in its applications in finer breaking of the materials.

(3) Vibrating Spreader and Vibrating Roller

Vibrating Spreader and Vibrating Roller are the key equipment in the road construction and are the typical application of the vibration technology. A vibrating spreader first spreads materials onto the whole width of the road, and then uses the exciter of the rolling mechanism to roll the road surface. The vibration system is the key device to determine the effects of spreading the materials and density and the quality of the spreading and rolling.

There are the vibrating motors mounted on the connecting plate in the vibrating rollers. The motors drive two eccentric shafts to rotate in opposite directions at high speeds. The eccentric lumps on the shafts generate the centrifuge forces to drive the vibrating rollers into the forced vibrations to roll the road surface. The amplitude adjusters mounted on the eccentric drafts are used to adjust the vibration amplitudes. The introduction of the vibration increases the density of the rolled surface from 90% to above 95% and improves the quality and usage life of the roads.

(4) Vibrating Forming and Technology

The Vibrating Forming on the metal and porous materials can greatly reduce the energy consumed and improve the quality of the parts formed compared to the static force forming. The test data show that introducing the vibration in the processes of metal plastic processing can reduce the energy consuming, increase efficiency, and improve the processed part quality.

(5) Vibration Ageing

Vibrating Ageing can reduce the internal residual stresses of metal parts to some extent, and stabilize the sizes and shapes of the parts after processing. The Vibrating Ageing is to exert the periodical forces on the parts and force the parts vibrate in the frequency range of their resonance. The periodical dynamic forces make metal atoms in the internal structure generate displacement and crystal lace dislocations and thus relax the stresses. A vibrating ageing equipment generally includes an

exciting device, a vibration measuring unit and a control device for dynamic stress. Compared to heat treatment, the vibrating ageing has advantages of easy operation, less transportation, short period of production and consuming less energy and is a new technology of saving energy.

(6) Vibrating Diagnostics and Vibration Measurement Technology

Diagnosing the faults by analyzing the different characteristics of the vibration signals from the machines and structures is a new technology developed in recent decade. It is widely used to analyze and diagnose the vibration signals by the Fuzzy Theory, Gray Theory or Neural Network.

(7) Vibrating Equipment and Device for Exercise and Sports

Vibrating Massager belongs to this type. Many Work-out and sports equipment are made use of the vibration technique and becomes an indispensable sport device.

(8) Mechanical Medical Equipment Instrument and Device

The Artificial Hearts and Heart Pacer are all the medical devices using vibration principles.

1.3 Applications and Developments of Nonlinear Vibration Utilization Technology

The vibration machine and devices mentioned above can be classified into two types: linear or pseudo-linear (approximately linear) and nonlinear according to their linearity and non-linearity. In non-linear vibrating machines and equipment some of them using the non-linearity characteristics in the systems for better efficiency are applied intentionally, and others not intentionally but made use of the non-linearity naturally existed inherently (see Table 1.2 above).

(1) **Utilization of the vibrating systems with piece-wise friction or impact and piece-wise inertial forces**

In the vibrating machines, in order to have relative movement, i.e. the relative sliding or jump, between machine body and materials, the piece-wise friction force or mass inertial force (sliding movement), or impact force and piece-wise mass inertial (throwing movement) must be generated in the vibrating machines. These are the necessary conditions to keep the vibrating machines working normally. This type of machines is the vibrating feeder, conveyer, screen, centrifugal dehydrator and cooler, etc.

(2) **Utilization of Smooth nonlinear vibration system**

Friction pendulum belongs to smooth nonlinear vibration system in its normally working neighborhood. The friction pendulum can be used to measure the friction coefficient between axial and axial bushing. There are two methods to do it: The first one is to use the decay value of the every vibration period of the double pendulum to directly calculate the friction coefficient; the second is to use the working principle of the Flode pendulum to measure and calculate the friction coefficient. The latter is more accurate than the former.

For some vibrating machines working in resonance frequency range, such as electric–magnetic vibration feeder, near-resonant vibrating conveyer and resonant screen, their amplitudes are not stable. To overcome such shortcomings, the smooth harden type of non-linear restoring force vibration machines may be used.

It is pointed out that the two fixed ends of the main resonant leaf springs in the electric–magnetic vibration feeder can be made the curved shapes so that as the vibration amplitude increases the working length of the leaf springs will be shortened, therefore their stiffness will increase as a result which in turns stabilize the vibration amplitudes for these kinds of machines.

Besides, the harden type of smooth nonlinear vibration systems can also be used to the vibration isolation of vehicles. Vehicle loads change from time to time in order to keep its resonant frequency not change obviously when its loads are changing, the isolation springs can be made the harden type smooth nonlinear system.

(3) **Utilization of Piece-Wise-Linear Nonlinear Vibration Systems**

Piece-wise-linear nonlinear systems have been applied to nonlinear vibrating conveyors, nonlinear vibrating screens, nonlinear vibrating centrifugal dehydrators, vibrating and vibrating centrifugal table. The piece-wise-linear nonlinear vibration systems are generally classified as three categories:

(1) Total symmetric and non-symmetric harden type of piece-wise-linear nonlinear vibration systems.
(2) Symmetric and non-symmetric soften type of piece-wise-linear nonlinear vibration systems.
(3) Compound or complex type of piece-wise-linear nonlinear vibration systems.

Those types of the vibrating machines have many advantages: they are in the process of constant promotion and are expected to be developed further.

(4) **Utilization of Nonlinear Hysteric Systems**

The vibration systems with elastic–plastic deformation belong to this category, such as vibrating shape machine, Vibrating Roller, Vibrating pulling pile machine. Their vibration systems belong to the nonlinear vibration systems with hysteric restoring forces. In order for he vibrating-shape machines to work effectively the plastic deformation is necessary and must increase the area of the Hysteresis loop as much as possible. This kind of vibrating machines exists widely in the engineering. The categories of this type of vibrating machines are as follows:

(1) The nonlinear vibration systems with parallelogram Hysteresis restoring forces;
(2) The nonlinear vibration systems with closed Hysteresis loop restoring forces;
(3) The nonlinear vibration systems with asymmetric restoring forces;
(4) The nonlinear vibration systems with gap Hysteresis restoring forces.

In our studies we have conducted deep researches on this type of non-linear systems.

(5) **Utilization of Self-excitation Nonlinear Vibration Systems**

In engineering the self-exciting vibration systems have been widely used. For examples the pneumatic and hydraulic rock drill and stone crusher in mining industry, air pick in coal industry, air shovel in a casting shop, steam hammer in a forging shop, non-piston pneumatic eliminator in coal depressing plant. The working process of the steam engines, reciprocal oil cylinder or a variety of mechanisms composed of parts driven by pistons, is also self-excited. In radio communications and instrument industry the electronic oscillators in radio and television circuits, the wave generators in a variety of instrumental display devices; switch type of temperature adjustors in constant temperature containers, watch and clocks in everyday life; the string music instruments. Heart beating is a self-excited as well.

(6) **Utilization of impact nonlinear vibration systems**

The technological utilization accomplished by impact is frog rammer, impact pile machine, vibrating sand remover and vibrating drills with impact. The impact type of vibrating machine is a special example of the non-linear vibrating machines. By theory computation and experiment verification, the instant acceleration generated under the impact situation is several, even hundreds of times compared to the maximum acceleration generated by a general linear vibrating machine. Making use of such a big impact force, we can accomplish many works, such as ramming road surface, removing sands from forged parts and crushing rocks.

(7) **Utilization of slowly-changing parameter vibration systems**

In engineering, many working processes belong to slow-changing parameter systems. For examples the working process of the controls on vibrations of the rotating machines is a kind of the slow-changing parameter systems. The speed of the slow-changing process will affect directly on the vibrating amplitudes controlled. Therefore we may make use of the speed of the slow-changing control process to achieve the optimal control effects. For example, for a rotor system with slow-changing parameters, the startup and braking process, the exciting frequency slow-changing will make the resonant curve generate a shift and affect its stability, rotor stiffness slow-changing will make the unstable resonant curve shift. For the roller system of slow-changing support stiffness, if we choose a proper stiffness slow-changing speed, we could effectively constrain the vibration passing the resonant region. From this example we can see that the slow-changing parameter systems can be made use of in industry.

(8) **Utilization of Frequency Entrainment Principles**

In engineering the frequency entrainment phenomena have been used widely. The realization for this principle is that two induction motors, parallelly installed on the same vibrating system, drive two eccentric rotor exciters separately. Nowadays there are millions of such self-synchronous vibrating machines based on this principle. Test shows that two exciting motors operate separately their rotations per minute (RPM) are 962 rpm and 940 rpm respectively. their rotations are all 950 rpm while they operate together. This is called frequency entrainment. In its engineering utilizations, for example, the two induction motors drive two eccentric rotor exciters which are installed to the same vibrating system.

(9) **Utilization of Bifurcation Solution**

Some of the bifurcation solutions for nonlinear equation can be utilized and others can not. Therefore the study on the solution has an engineering significance. For example the effective working zone for a frog rammer is the maximum impact speed zone of its periodic movements, i.e. the bifurcation solution of the periodic movements. The movements of the materials in the vibrating conveyers have many bifurcation solutions, equal-periodical jump, double periodical jump, triple periodical jump and n-periodic jump and non-periodical jumps. Selecting the most ideal, or the movement forms which have the optimized technological index and other parameters, is the most valuable and most important research topics.

(10) **Engineering Utilization of Chaos**

Chaos has a wide range of utilization. For example, cancel the vibration of the boring shaft in a boring machine by the chaos movement of the steel balls in the vibration cavity in an impact vibration absorber; accelerate the mix of the materials by chaos movement of the multi materials in a vibrating mixer; some people even tried to speed up the mix of materials by Chaos. The chaos has the unique unpredictable characteristics and thus has been successfully utilized to encrypt the confidential communication systems.

In addition, some harmful instable vibrations may occur in some nonlinear systems. In these cases, we should try to transit the unfavorable vibration to favorable chaos movements. This is naturally a way of utilizing the chaos movement. However is there another more effective measure than chaos movements? It is a worth-study question.

1.4 Applications and Developments of Wave Motion and Wave Energy Utilization Technology

Utilization of wave motion and wave energy is a new direction in vibration utilization in engineering fields in the recent decade. Scientists in the world did a lot of research on it and many results have been applied. The subject is still under study and development (see Table 1.3).

Table 1.3 Classification and usage of wave and wave energy

Type of waves	Usage	Device and equipment name
Utilization of sea wave and tides (water wave and wave energy)	Sea wave and tidal electric generation, tidal transportation	Tidal electricity generator, tidal power station, tidal transportation device and ships
Utilization of elastic wave (stress wave)	Vibration oil extraction, vibration exploration, column test, structure health diagnostics	Vibration oil extraction equipment, geology exploration vehicle, vibration exciter for column test
Utilization of subsonic and sound wave	Equipment and structure diagnostics	Subsonic wave generator
Utilization of ultrasound	Ultrasound Motor, ultrasound water-fuel mixing, ultrasound medical treatment (color ultrasound, ultrasound calculus smashing Ultrasound Diagnostics	Ultrasound motor, ultrasound fuel-water-mixer, ultrasound medical equipment, color ultrasound, ultrasound calculus crusher, ultrasound washer
Utilization of ultraviolet wave and microwave	Ultraviolet disinfection, microwave heating, microwave communication	Ultraviolet wave generator, microwave oven, microwave communication equipment
Utilization of visible light wave	Heating, laser technology fiber-optic technology	Water-heater, laser machining, fiber-optic communication
Utilization of infrared wave	Heating, imaging, medical treatment, military reconnaissance	Heater, thermal-imaging, infrared medical equipment, infrared military reconnaissance and monitoring equipments
Utilization of X-ray wave, γ-ray wave and β-ray wave	Medical treatment, diagnostics	X-ray machine, medical CT, industry CT, β ray medical equipment and other monitoring and diagnostics devices

1.5 Applications of Electrics, Magnetic and Light Oscillators in Engineering Technology

The rapid development and application of the big information capacity satellites and satellite live broadcasting lead to the more and more light-electric device and instruments based on the vibration principles being used. For examples, the quartz oscillators in the watches and clocks, light-fiber vibration sensors, electronic timing devices, and the oscillators used in the communication systems and ultrasound devices as shown in Table 1.4.

(1) Electronic Oscillator

The application of the electronic oscillators to watch industry starts a very important revolution in the watch industry. Until now most of the mechanical watches are replaced by the electronic watches.

(2) Ringtone Circuit and Electronic Music

The electronic Ringtone Circuits, which are small in volume, light in weight and pleasant in sound, have been used in cell phones. The core element of the ringtone circuit is the specialized integrated circuit composed of a rectifying circuit and an oscillating circuit. The ring input signal is rectified by the rectifying circuit into a direct-current (DC) voltage about 10 V. The DC voltage was fed into the oscillating circuit, which outputs signals in two frequencies. The output signals, modulated by an ultra-low frequency oscillator, are fed into an amplifier. The amplified signals then are sent to a piezoelectric ceramic or to a transformer to match impedance, to broadcast the ringtone.

The electronic music is a sound created by oscillators of different frequencies then output via some rhythms and different frequencies by a computer.

(3) Piezoelectric Ceramics Electric–Magnetic Oscillator

Table 1.4 Type and usage of the oscillators

Type of oscillators	Usage	Device names
Electronic oscillator	Electronic watch, electronic wall clock, electronic music, etc.	Electronic watch, electronic clock, electronic instruments, radio, TV, walkie-talkie, signal generator
EM oscillator	Telephone, piezoelectric ceramic oscillation circuit, etc.	Telephone, ringtone, magnetic deformation ultrasound generator, piezoelectric ceramic oscillation circuit, etc.
Laser oscillator	Laser oscillation circuit, etc.	Laser oscillator, etc.

(1) Sea Wave Electricity Generation

Oceans cover about 71% of the surface of the Earth and contain 97% of water in the world. The inexhaustible water resource is the new hope of the new energy for the twenty-first century. The oceanographers estimate that the energy of the ocean wave would be as high as 90 trillion Kwh which is 500 times of the total electricity generation in the world.

Scientists noticed the sea wave electricity generation as early as in twentieth century. Scientists in The USA, Japan and Great Britain designed the sea wave electricity generation stations in the 90s in the last century and the efficiency of the station reached about 60%. The successful wave electricity generation unfolds the future application and development of the utilization of the sea wave energy for the human beings for the new century. Best of all, electricity generation by sea wave energy has no pollution, no negative biological effect on environment. This is one of reasons people put a great expectation on it.

Sea wave electricity generation station uses a pneumatic turbine which converts the energy, generated by guiding the sea wave into a narrow grotto, into electricity. The station uses a high efficient collecting and converting device. A computer controls everything, from wave-guide, electricity generator to electricity transmission. The first wave electricity station in China was installed in Pearl Delta, Guangdong Province. The station's pneumatic chamber is 3mx4m and two generators, 3Kwh and 5Kwh, have been installed. The station has a trumpet-shaped opening on the bank. The basic principle of generating electricity is that the pneumatic chamber converts the sea wave energy into the reciprocal movement of the air which is used to drive the generator to generate electricity.

(2) New technology for oil drilling by super low frequency controllable vibration source

The effect of the natural earthquakes and artificial earth surface vibration on the output of the gas and crude oil was brought to people's attention in the research on earthquake prediction. An oil well in Illinois, the US, is about 1,500 ft deep. When trains pass over on the surface the oil pressures in the well fluctuate and it has some effect on the oil output. The oil output increased 100%. The gas and oil outputs in Shengli, Daguang and Liaohe oil fields in China, before and after The Haicheng Earthquake in 1975 and The Tangshan Earthquake in 1976, had been increased obviously. Scientists note that compress and expansion waves of the Earth surface are the source of the micro additional pressures on the oil layers. It can increase the pressure to drive the oil and improve the fluidity of the oil. Both theory and simulation tests in labs show that vibration can increase the recovery ratio of the oil.

The author and my team participated in a project on the technology and achieved a great result. The controllable vibration excitation source used in the study is the surface vibration device. The device is a powerful double-rotor eccentric type of exciter. It consists of an alternative speed-adjustable motor, a gearbox and two eccentrics which rotate relatively. A distributor and a controller adjust the frequencies and excitation forces of the vibrations. The symmetry in the structure makes the