The State and Development of Tribology Research in China

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Abstracts :

Main achievements of tribology research in China during the past 25 years were summarized, and several promising research fields are suggested accordingly.

Key words: tribology research; the current state; future research fields

1. Introduction

In the middle of 1960's, British department of education and science published 《Lubrication (Tribology) Education and Research》firstly tabled a proposal that tribology should be treated as an independent interdisciplinary subject discipline. Strengthening research and education in tribology had great strategic effect on promoting sustainable development in national economy. Soon the concept attained general recognition all over the world. Subsequently, tribology developed quickly and became one of the most active research fields in mechanical engineering and materials science [1].

Because of various historical reasons, tribology research in China started relatively late. Although several scholars carried out their investigations on wear and lubrication as early as in 1950's, as an independent discipline, research and educational work in tribology had just steadily developed since 1980's.

In 1979, Tribology Division of Chinese Mechanical Engineering Society (TDCMES) was founded. In the past 25 years, through efforts from various fields, the discipline of Tribology in China has made great progress. Knowledge of Tribology popularized extensively; A research team specialized in Tribology was established, including "Yangtse Scholars", "NSFC funds for outstanding young man" receivers and so on, who were young or middle aged academic backbones; National class, province or ministerial class research platforms were founded; Specialized academic publications were originated, tens of academic monographs and scientific books were published. On the promotion of related academic organizations, diversified nationwide or provincial academic conferences were held, achievements were exchanged and discussed; and international academic activities

were frequent. International academic conferences were held many times in China and the 1st AsiaTrib was successfully held in China. Meanwhile, Chinese scholars were active in the international academic stages of tribology. The development of tribology in China combined closely with national economic construction. It greatly promoted the national modernization construction, rapidly improved tribological performance of mechatronic products.

Through long term practicing, Chinese tribologists not only did well in solving engineering problems but also concentrated on improving the depth and width of research field. The development trends of tribology in China can be generalized as: transition from maintenance of mechanical products to tribological design for new products; from simply catching-up research to innovative research; from local object of single discipline to multi-disciplines systematic research; from the investigation of macroscopical characteristics to opening out microcosmic mechanisms, building essential relationships among tribological phenomenon; promoting cross link between tribology and related disciplines, making great efforts to set up new research fields such as microtribology, biotribology, ecotribology etc.

On the basis of author's understanding and presently gathered information, this article tries to briefly describe the progress of tribology in China and prospect on the future investigation. The content is author's individual opinion.

2. Achievements

(1) Research on fluid lubrication and sliding bearings

The lubrication design based on fluid lubrication theory for surface contacts such as sliding bearings and sealing parts was an important problem in modern machinery design. Systematic investigation was carried out on lubrication design for high-speed radial sliding bearings in turbomachines such as steam electric generation sets and turbo-compressors. Such sliding bearings were elliptic bearings, multi-oil wedge bearings and tilting-pad bearings etc. The following work were conducted: Static (load carrying capacity, flux, friction loss) and dynamic performance calculations, taking into account of the heat effect and thermal deformation; Analyzing the pertinence between static or dynamic performance and structural or working condition parameters; Treating steam electric generation sets as background, the dynamics analysis for bearing-rotor systems was carried out, rotor's unsteady conditions and criterions were brought forward, meanwhile the causations for

instability of the steam electric generation sets were demonstrated [2]. On the basis of foregoing work, a design expert system was established in for the multi-support rotor system in steam electric generation sets.

Some achievements were obtained in the research of hydrostatic bearings whose application background was for high-precision machine tool spindles. Shallow antrun static/dynamic compound bearing design was put forward and predominant lubricating performance was achieved compared with conventional configuration [3]; Hydrostatic bearings were widely used to reconstruct spindle support of grinding machines so as to improve the rotation accuracy, economic benefits were manifest.

Gas hydrostatic lubricating bearings were successfully designed for high-speed spindles and other devices, especially various airproof devices with spiral grooves based on gas dynamic pressure had superior capability. It is now industrialized and sold all over the world.

Extensive investigation was carried out on combustion engines, including materials, configuration and lubrication design of every friction pair. Engine performance was prominently enhanced. Intelligent design theory and methods with tribological considerations were put forward and related software system was developed [4].

(2) Elasto-Hydrodynamic Lubrication and its applications

The lubrication design of point and line contacts such as gear and worm drives was based on elasto-hydrodynamic lubrication (EHL) theory, and great successes were achieved. Considering the various factors in engineering conditions, the elasto-hydrodynamic model with thermal effect, the elasto-hydrodynamic model with non-Newtonian lubricants, the unsteady elasto-hydrodynamic model with altering working conditions were developed. On the basis of these models, a set of lubrication equations with the highest applicability were developed and solved so as to establish theories of the elasto-hydrodynamic lubrication used for engineering model with various effects of practical factors, which were considered as self-contained full-film lubrication theory nowadays [5,6]. In application research, an optimized lubrication design was put on stop ring of the roller bearings used in railway and the axial loading capacity was greatly improved; The theory was used in lubrication analysis of the roller bearings in satellites, judging principles for oil starvation and dry lubrication conditions were established and bearing's working life was doubly increased; A new type of worm drives was devised with combination between EHL and engagement theory and loading capacity was increased.

In allusion to contacts of 3D conjugate surfaces, EHL with non-Hertz contact theory was developed, including flat ellipse contact, non-alignment of the entrainment velocity with the main plane and contact with rotating, and applied in lubrication analysis of bevel gear drives.

Zero entrainment velocity thermal elasto-hydrodynamic was found to have loading capacity due to temperature wedge. The idea was theoretically analyzed and validated by experiments, so theoretical reference would be provided to the design of high-speed non-retainer roller bearings.

Failure of lubrication films existed in engineering for a long time and some fundamental research was carried out on it. For instance, on the basis of asperity micro-EHL research, the derivation of mixed lubrication in real rough surfaces contact was implemented; In rheologic EHL research, a viscoplastic rheological model was investigated and mechanisms of lubrication films slipping, yielding and then losing loading capacity were illustrated, which indicated that the limiting shear strength had important effects on failure of lubrication. According to EHL analysis on viscoplastic rheological model and viscoelastic effect of solids, the possibility of wear and forming of debris were demonstrated in the situation of full film lubrication.

In experimental research, a series of testing techniques for the measurement of elasto-hydrodynamic lubrication film thickness were developed. For example, film thickness measuring with optical interference and temperature measuring with distortion field and infrared radiation, pressure distribution measuring of oil with thin-film sensor and high pressure viscosity measuring device, all of which had reached world advanced levels. Furthermore, nanometer scale film thickness measuring apparatus was firstly originated.

(3) Microtribology Research

Research on microtribology applied in ultra-precision machines and MEMS was started early and achievements were notable [7].

Important initiative contributions were done in the research on thin-film lubrication with nanometer scale characteristics. Through systematic research, pertinence of surface effects on thin-film lubrication behaviors was investigated; Physical model of nanometer film with adsorption film, ordered fluid film and viscous fluid film was brought forward. The transform relationships from thin-film lubrication to boundary lubrication and EHL states were established. The rheological characteristics (including wall effects,

solidification and phase transformation etc) of the restricted fluids in nanometer gaps were studied [8]; Numerical analysis was carried out on thin-film lubrication performance with various micro hydro-models and also served as guide for lubrication theory considering microstructures of thin-film. So self-sealing fluid dynamic bearings were primarily developed using thin-film lubrication concept, which could run at high speed without continuously supplying lubricant.

Through in-depth research on physical and chemical behaviors as well as nanometer scale wear in contacting surfaces, great developments were achieved in lapping technology for ultra-precision planes. The polishing and modification techniques of magnetic head/disk were advanced in the world, some capacities were leading and applied to mass production.

Our research on ordered molecular film lubrication had notable achievements, many kinds of self-assembled films, molecular deposition films [9] were developed. Effective explorations were carried out on molecular film strengthening, enhancing hydrophobicity of surfaces, improving loading capacity and combination of general additive and nano-particles.

Microwear was a critical problem in MEMS. It was difficult to be investigated in this field not only in theory but also in experiments. Firstly many kinds of experimental sets and measuring devices used for microwear research were developed. Theoretical analysis methods based on molecular dynamics were established. Furthermore, surface behaviors and mechanisms on dry lubrication interfaces were investigated in atomic and molecular scale; several phenomenon which was related to surface energy such as adhesion, conglutination and stick slip were studied and restraining techniques were considered. The feasibility of approximately zero-friction ultra slippery techniques were demonstrated by experiments [7].

Microcosmic wear has close relations with surface topography. So microcosmic topography of the surfaces machined with high-energy beam and the relations between microcosmic wear and topography were studied so as to control wear through surface topographical design and decoration. Through outside electric field and magnetic field, the performance of wear could be improved.

Surface coating was another way to improve nano-tribology performance. Some application achievements in ultra hard coating such as diamond film, quasi-diamond film and carbon nitrogen film were accomplished, even in multilayer film altered with soft and hard phases were investigated and practical results were obtained.

(4) Research on abrasion of metallic materials

Concerning research on metallic materials' abrasion, our scholars had obtained significant achievements in grain-abrasion, fretting wear and corrosive wear.

Grain-abrasion and wear resistant materials were one of the most active fields [10]. Because grain-abrasion was the main abrasion type in metallurgy, building materials, colliery and agricultural machinery, on which millions of steels were consumed. So production sector and research institutions got together to tackle the key problem for economical consideration. Under the guidance of underling special committees of CSME and Chinese Society of Chemistry, tens of national-wide academic exchanges conferences on wear resistant and failure analysis of abrasion were held, communication activities on performance evaluation for mills' ball and crusher's tooth were organized and collaborative network in wear resistant materials among different areas were established [11]. Through all of the activities, the quality of wear resistant materials was improved, new materials and techniques were put forward, as a result the activities promoted in-depth investigation on the mechanism of grain-abrasion.

Chinese scholars had made systemic contributions [12] to mechanisms and defense for fretting wear, including: the fretting picture which could illustrate the fretting course was brought forward and fretting area was divided into slip area, partly-slip area and mixed area; crack germination and extending manners in fretting damnification were opened out; the relationships between fretting wear and fretting fatigue; materials' surface strengthening and defense of fretting fatigue with lubrication were investigated. These theories were applied to fretting fatigue analysis and defense in upper air cable and cable stayed bridge, results were notable.

Corrosive wear, which was different from commonly abrasion and corrosion phenomena, was a severe damnification type of material loss process due to the interaction between dynamic and chemical effects and consequently became relatively difficult and late-starting field in tribology. Our research on corrosive wear was integrated into production in allusion to defense for work pieces in paddy field's cultivation, slime circulating pumps in petrochemical industry, transportation light rail in colliery and pipelines in coal burning boiler, and prominent effect was obtained. The most important goals in fundamental investigations were: corrosive wear and performance testing devices, mechanisms in corrosive wear, design of corrosive wear resistant alloys and development for new materials, performance of corrosion resistant surface coating, etc. Our research on corrosive wear came into being considerable scope. The 1st academic conference of China on corrosive

wear was held in 1996. The monograph published in 2003 generally described this damnification type from the interaction between abrasion and corrosion [13].

(5) Research on tribology of nonmetallic materials

Besides research on bearing-bushes in hydraulic turbine that were made from ceramic materials, metallic plastics and elastic composite materials, major achievements in nonmetallic materials were research on rubber abrasion, development and industrialization for water-lubricated nonmetallic bearings.

As a particular tribological material, rubber was widely used in vehicles and petroleum industry. However, up to now, tribological reports on rubber were spare. Our scholars carried on systemic research on grain-abrasion and corrosive wear in allusion to rubber abrasion. Three characteristics of grain-abrasion that were dry grain, oily grain and waterish grain were investigated. Mechanism of rubber corrosive wear was researched and grain-corrasion model was put forward. Also surface force's chemical effect in grain-corrasion including caoutchouc, butadiene nitrile rubber, fluorine rubber and polyurethane were analyzed [14].

Nowadays there were totally two millions of various kinds of watercrafts in China. The leakage of lubricating oil in propulsion system reached one million tons and caused severe water pollution. Traditional synthetic rubber or lignum vitae water-lubricated bearings were power-consumed and usually had short service life. The nonmetallic composite water-lubricated bearings which were developed by Chinese had excellent handling performance and were industrialized, marketed all over the world, which had brought significant economic and social benefits.

(6) Surface engineering and its application

Since the international tribology conference where importance of surface engineering was emphasized on had been held in London at 1987, Chinese scholars had paid wide attention to surface engineering. From then on, application research on surface modification and coating techniques became one of the most active fields in tribology and plentiful productions were obtained. Frictional wear performance of numerous machine elements was improved universally and considerable economic and social advantages were obtained.

Surface engineering was a series of techniques in which the surfaces obtained appropriate element, structure and capability by means of physical, chemical and mechanical methods, including surface heat treatment and chemical heat treatment, electroplating and electrodepositing, build-up welding and hot spraying, high heat-flux processing and vapor deposition, etc [15]. All of the techniques and application researches above were developed

in China. It was difficult to describe one by one. In recent years composite surface combining with multi techniques and advanced ultrasonic hot spraying technique were developed [16].

(7) Research on lubricative materials

Lubricative materials and lubrication theory was an important part of tribology. Along with the development of science and technology, especially evolution of the lubrication chemistry, new types of high-performance lubrication materials came out unceasingly in the past 25 years.

China had vast territory and the differences between regions were big. Also the requirements for the performance of lubricative materials were various in industrial, agricultural and national defence departments. In order to adapt practical demands, our scholars had developed various kinds of new pattern lubricative materials including lanthanon and liquid crystal materials [17] for lubrication. What should be pointed out were Chinese scholars' outstanding contributions to research on solid lubrication with high temperature or severe working conditions in aerospace fields, in which we had gained a leading position.

Professor Yan Zhiguang(editor-in-chief) published <Practical manual for new type of lubricative materials and lubrication techniques>(National defence industry press, 1999). In this book, domestic and overseas research productions were gathered, the performance, standards, testing and application examples were expatiated about lubricative materials and techniques [18].

(8)Iron spectrum and inspection of abrasion state

It was indicated in practice that iron spectrum techniques had received identification from various industry department as an effective method for inspection of abrasion state and fault diagnosis.

The appearance of oil-analyzing techniques would date back to 1940s, when the abrasive microelements in lubricant were analyzed by spectrograph and the abrasion state was clear. In 1970s, iron spectrum detector that could test the configuration of abrasive grain was invented, so oil-analyzing techniques became more efficient.

Chinese researchers had developed analytical-style iron spectrum detectors and direct reading ones separately at 1983 and 1985, mass production were carried on. As a result, we became a country with relative large number of iron spectrum detectors.

The application of iron spectrum detectors to diesel engine, gear case, hydraulic pressure system for abrasive state inspection was carried through and lots of successful examples

were implemented with datum accumulation. For instance, on the basis of 229 diesel rail cars and other devices, 1600 or more iron spectrum analysis for oil swatches and 2500 pictures were obtained, typical grains' iron spectrum pictures were picked out and systemic spectrums of graph were illustrated, which was a matured symbol of oil-analysis techniques with iron spectrum detectors [19]. Furthermore, in order to judging the abrasive state all-around, multi-information fusion techniques based on iron spectrum analysis, spectral analysis and oil analysis were brought forward and frameworks of fault diagnosis expert system were established.

3. Prospect

Tribology, as a technique fundamental subject, will inevitably be driven by the modern scientific technology and the economic development. The research content and method of tribology should be improved by absorbing advanced techniques of related disciplines. Also, tribologists should try to improve the tribological property of the products to satisfy the economic development. So, besides the efforts to further enrich and enhance the present research area and results, the Chinese tribologists should pay enough attention to the development of the following research topics [21,22], (1) Lubricate and anti-wear technique, (2) ecological tribology, (3) extraordinary (ultra-parameter) machine tribology, (4) tribology on special geography conditions, (5) manufacturing tribology, (6) abrasion failure inspection of big whole set machine system, (7) bio-mimic and biological tribology, (8) grain tribology.

References

[1] Wen Shizhu, Principles of Tribology (the 1st Edition), Tsinghua University Press, 1990; Wen Shizhu, Huang Ping, Principles of Tribology (the 2nd Edition), Tsinghua University Press, 2002

[2] Yu LieLiu Heng, Bearing-rotor system dynamics, Xian Jiaotong University Press, 2001

[3] Chi Changqing, Hydrodynamics Lubrication, Defense Industry Press, 1998

[4] Zhang X.J., Gui C.L., An Intelligent Systems for Tribological Design in Engines, Elsevier, 2004

[5] Wen Shizhu, Yang Peiran, Elasto-hydrodynamic lubrication, Tsinghua University Press, 1992

[6] Yang Peiran, Numerical analysis of Hydrodynamics, Defense Industry Press, 1998

[7] Wen Shizhu, Nano-Tribology, Tsinghua University Press, 1998

[8] Jianbin Luo, Shizhu Wen, Measuring Technique and Characteristics of Thin Film Lubrication, in《Mechanical Tribology》Totten & Liang ed., Marcel Dekker. Inc. 2004

[9] Xue Qunji, Zhang Jun, Ultra-thin film of regular molecular system and its application in tribology, Liaoning Science and Technology Press, 1995

[10] LiuJiajun,edited,Principleofmaterialwearanditsanti-grinding,TsinghuaUniversity Press, 1993

[11] Division of wear failure analysis and prevention, edited by the State Key Laboratory of Tribology, Anti-wear materials and wear failure analysis, Mechanical Industry Press, 1993

[12] Zhou Zhongrong et al., Fretting wear, Scientific Press, 2002

[13] Jiang Xiaoxia, Li Shizuo, Li Shu, Corrosion and abrasion of metallic materials , Chemical Industry Press of China, 2003

[14] Zhang Shiwei, Elements of rubber abrasionPetroleum Industry Press of China, 1998

[15] Xu Binshi, Zhu Shaohua, Theory and Technology in Surface Engineering, Defense Industry Press of China, 1999

[16] XuBinshi,edited,Nanosurfaceengineering,ChemicalIndustryPressofChina,2004

[17] Dong Junxiu, Principles of Lubrication and lubrication oil, Hydrocarbon Manufacturing Press, 1987

[18] Edited by Yan Zhiguang, Practical manual for new type of lubricative materials and lubrication techniques, Defense Industry Press of China, 1999

[19] Yang Qiming, Grain analysis-grain picture spectrum and iron spectrum technique, Railroad Press of China, 2002

[20] Edited by Zhou Zhongrong, Xie Youbai, Tribology Design, South-West Jiaotong University Press, 2000

[21] Edited by Wen Shizhu, Li Ming, Research on development strategy of Mechanology, Tsinghua University Press, China, 2003

[22] Wen Shizhu, Century review and prospect- development and trend in tribology research, Chinese Journal of Mechanical Engineering, 36(6): 1-6 (2004)

[23] Translated by Li Jian, et al., Micro/Nano biological tribology, Mechanical Industry Press of China, 2004

Prof. Wen Shizhu was born in 1932. He graduated from Department of Mechanical Manufacture at Tsinghua University in 1955, and then joined the faculty of Tsinghua Universty. In 1979, Prof. Wen went to the Imperial College of Science and Technology, London University, as a visiting scholar majoring in tribology. From 1981 to now, Prof. Wen has been the director of Institute of Tribology at Tsinghua University, the director of the State Key Laboratory of Tribology. Now he also serves as the chair of the Academic Committee of Department of Precision Instruments and Mechnology at Tsinghua University. Prof. Wen has mainly devoted himself to the basic research on tribology. He has finished and directed more than 20 research projects, which are mainly from National Science Foundation of China, National Science and Technology Committee and other international cooperating items. His research fields cover lubrication theory, friction and wear mechanism and control, nanotribology and micromechanology. Prof. Wen has published 5 academic books and more than 400 research papers. By now, he and his colleagues have been honored 18 items of awards, including the National Award in Natural Science (2nd rank), National invention Award (3rd rank), National Excellent Book Award (1st rank and 3rd rank), Ho Leung Ho Lee Prize (Technological Science Prize of 2002), etc. In 1999, Prof. Wen was elected as the member of the Chinese Academy of Sciences.

논 문 발 표

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