Three Axioms in Tribology

Xie, You-Bai
Theory of Lubrication and Bearing Institute,
Xi'an Jiaotong University
Xi'an 710049, CHINA
E-mail: ybxie@xjtu.edu.cn

ABSTRACT

The undesired situation of development of tribology and its reason is analyzed. The problem comes from insufficient study on the concept system and method system, which can match the name, definition and nature of tribology. The existence of three axioms in tribology is discussed. They are **axiom of system dependent**, **axiom of time dependent** and **axiom of coupling of behaviors of multi-discipline**. A series of lemmas has been deduced from three axioms. It is expected that they can be a foundation to establish the concept system and method system.

Key Words: tribology, axiom, system-dependent, time-dependent, behavior coupling

INTRODUCTION

What is tribology? Some people say that tribology is friction, wear or lubrication. Others say it is friction plus wear plus lubrication. In general both of them are not right enough. Tribology inherits all of the theoretical and applied results from friction, wear and lubrication obtained in thousands of years and inputs into them with more abundant meaning and contents based on the development of science and technology and on the foresight of future.

The earlier stage of application of knowledge of friction, wear and lubrication in human productive and living practice can be traced back to 3000 BC or earlier [1]. This multi-discipline and its widely applicable field were studied independently in many different branches of science and technology from very different points of view over a long period. A suggestion from H Peter Jost gave this old field a powerful impetus and poured into it youthful vigor [2]. Therefore tribology is a both old and young discipline.

In the first phase of development of tribology due to its universal existence in nature according to the definition given by Jost in one hand and in another hand that the tribologists in many countries believe that they can make huge benefit in astronomical figures for their industry the extension of its influence is dramatically fast. Promise of a save of 5 billion pounds per year in UK from estimation in the Jost Report pushed forward tribologists working on applying existed knowledge of friction, wear and lubrication in solving engineering problems. Rapid increase of new techniques relative to friction, wear and lubrication appeared in the following phase even though some people they did not like the name 'tribology', for example the American. Many books published in this stage with the title 'Tribology' but no one explained what was tribology and why we coined the word 'tribology' other than Jost Report.

The later situation has shown that it is not easy to achieve the potential benefit

[3,4]. A name, a definition and simply putting all knowledge components together are not enough. A concept system and method system, which are suitable to the name, definition and nature of tribology and then can promote an independent development and application of tribology, are expected.

It is valuable to mention that 'Tribology' was defined as one of the four major disciplines of Mechanical Systems by a Committee of NSF of US in 1983 [5] and then the 'Journal of Lubrication Technology' was renamed as 'Journal of Tribology' of Transaction of ASME. Only ten years later, J Larsen Basse indicated in Beijing that a change under way was the gradual disappearance of the term 'tribology' from programs and projects of NSF in US [6]. In this period fewer papers, which dealt with the relation between tribology and mechanical systems could be found in the journal. It implies that no enough effort has been made to carry out the original intention. Larsen Basse described the different focal points of different phases in the history of development of tribology: in the earlier phase, it was friction (Coulomb), then lubrication (Reynolds), then wear and would become surface engineering later.

Other stories can be mentioned that a famous tribologist from France prophesied also that tribology would be instead by surface engineering (or become surface engineering). Another famous professor from UK said that tribology was only a kind of fashion.

This is not an alarmist talk. It shows some undesired situation for the development of tribology. There are at least three problems with tribology. Firstly tribology was born on the foundation of known phenomena of friction, wear and lubrication but the relation between tribology and friction, wear and lubrication has not been paid attention to investigate. Naturally the way of investigating friction, wear and lubrication independently is still been kept for tribology. In other words, there is no concept system and method system, which can match the name and definition of tribology. Many people they work in the field of tribology but they don't think they are tribologists. Some of them think they are chemists, material engineers or mechanical scientists. Secondly as tribology is so universal and so important to the mechanical systems much attention has been paid to the tribology based applied techniques and a very fast development of the techniques has been achieved. Surface engineering is one example. Technique of condition monitoring, fault diagnosis and maintenance is another example. The ratio of tribological failure in total failure amount is different in different systems. For example in large water turbine generator sets fault due to thrust pad seizure takes a factor about 50-70%. Needs of condition monitoring, fault diagnosis and maintenance is closely connected with tribology. Thirdly due to lack of tribology based theoretical and mothodological results in different specific areas a trend of developing their own specific tribology is carried out, such as 'polymer tribology', 'ceramic tribology', 'automotive tribology' or 'nanometer tribology' etc. Almost no one can answer whether results obtained in one specific area can be used in another area. Otherwise people have to use very old models, for example, in control engineering Coulomb friction model is still in use. The fact that methods independent to dynamics occupy dominant position in tribology is a brand of 'old machinery' deeply pressed on tribology. It is an identification of low speed and low precision. Many test machines, such Falax, Timken, Armsler or Four Ball Machine etc, are designed for lubricant performance test. Even though people know that such test machines cannot give an accurate answer for other purposes but they have to use them. They don't know the transforming relations for test results under different system conditions.

From the universality of tribology it is no doubt that tribology have a position in

engineering science just like the position of physics or chemistry in natural science. Young age makes it is not ripe enough like physics or chemistry. After its birth a growth and mature process is necessary. It takes time. On the other hand benefit in astronomical figures in application conceals the limitation on making more benefit due to the insufficient fundamental investigation. Benefit comes not from the appearance of word 'tribology' but from its universality.

In this paper three axioms are discussed. As a first phase of forming the concept system and method system of tribology, understanding what are specific for tribology, or different from known friction, wear and lubrication is an urgent need. So-called axioms mean what people cannot find any opposite example with the axioms even though they cannot prove them theoretically [7].

1. THREE AXIOMS IN TRIBOLOGY

1.1 First Axiom in Tribology: Tribological behavior is system dependent.

Behaviors taking place on the interacting surfaces in relative motion and between the surfaces are the contents of investigation in tribology and called tribological behaviors. Interaction and relative motion are the causes of behaviors and the results of behaviors are the phenomena observed in tribology. In Fig.1 there is a simplest tribological system including three elements called tribo-pair. If no lubricating medium exists it becomes a system of two elements. It is emphasized that the effect of interaction and relative motion they changes the intrinsic property of single elements and the behavior and then the phenomena cannot be carried out by any one of the elements. The character of system dependent can be found not only in the simplest system but also in any more complex system constituted of the simplest systems and their supporting sub-systems such as lubricating sub-systems, condition monitoring sub-systems and condition compensation or control sub-systems. It is one of the targets of investigation in tribology. First axiom focuses on the relationship of structures.

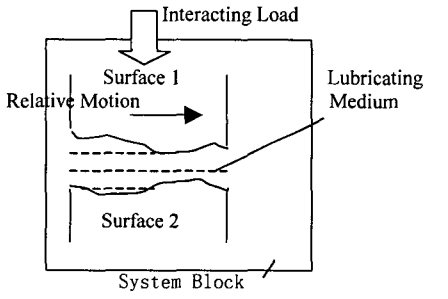

Fig. 1 Simplest Tribology System。

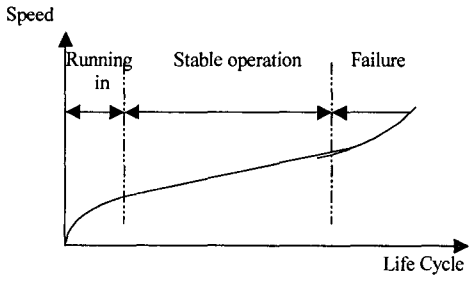

Fig. 2 Variation of the Speed of Change in Life Cycle.

1.2 Second Axiom in Tribology: Tribological behavior is time dependent.

In comparison with the material in the body of a component, the material of any element in a tribo-pair bears much more tremendous load and works under a much more severe condition. In the scope of a very small scale (in

consideration of the roughness of the surfaces the real contact area is much more smaller than the nominative contact area) the contact area transmits a load equal to what the cross section area of the component body transmits. The load density is therefore very large. The transmission is realized between different materials other than inside of the material of a component body. Meanwhile there is a relative motion. It accelerates the change of their chemical composition and geometry, especially that the change is continuously repeated, some times with very high frequency. Relative motion produces high temperature and other kinds of active energy and they will no doubt promote the change from physical aspect and chemical aspects. All of them make the change of the material as an element in the tribo-pair much more quick in comparison with what in the body of a component. Therefore what people usually considered as time-invariable must consider as time-variable during tribological analysis and tribological design. The speed of change is variable in life cycle. In earlier stage of work of a new system the change speed is high and it is called running in stage. Then the change will be smooth in the stable operation stage. At last the speed increases faster and the system is failure, Fig. 2. The pattern of variation of change speed is very complex in many systems. Another target of investigation in tribology is the pattern of variation.

1.3 Third Axiom in Tribology: Tribological behavior is the results of strong coupling of many behaviors of other disciplines.

From the simplest tribo-system in Figure 1, the force interacting and relative motion of surfaces and the medium between surfaces are mechanical behavior. The consumption of mechanical energy transforming into heat energy and diffusing into the surrounding, which makes a stable or unstable temperature field, is thermodynamic behavior and hear transfer behavior. The molecular interaction (including transferring) between surfaces and surfaces with medium is physical or physical-chemical behavior. The actions in ion level and atomic level are chemical behavior. If there is any electric or magnetic field and it produces attractive or repelling force, or changes the arrangement of molecules in materials, or induces eddy current or heat is electric behavior or magnetic behavior, and so on. There is obviously strong coupling between such behaviors. For any individual behavior it has its own discipline (theories and methods) to describe its pattern. Tribology is the science, which provides theories and methods investigating the pattern of coupling between behaviors under tribological condition. There is no other discipline, which can meet such a need. The difficulty for tribologists is that they have to know all the relative disciplines and tribology simultaneously. Such a character of inter-discipline and multi-discipline requires the methodology for tribology different from friction, wear or lubrication. In distinguish with the first axiom the third axiom focuses on the relationship of behaviors.

3. LEMMAS

Lemma 1: The property of any element in a tribo-pair is not the intrinsic property of the material constituting of the element but the property of the system constituted by them under given condition.

For example, there is no so-called stiffness for the fluid lubricant in figure 1 when it is in a free state. If it is in a cylinder container and applied a force from the top of the cylinder by a piston in axis direction (a given system condition), the stiffness of the fluid can defined as force divided by displacement of the piston when the deformation of the container is neglected. The same fluid exists between two surfaces

in relative motion with free boundary (another system condition) the stiffness with similar definition (only the piston is changed into an upper surface) depends on velocity, direction of relative motion, geometry of the space between surfaces and the viscosity of fluid.

The friction coefficient between surfaces under static condition is different from vibration condition and is different after different time from static condition. Many other system condition influence friction therefore it is very complex in application.

A distinct line can be drawn between surface engineering and tribology. When one deals with a surface and to improve the performance of the surface for better application he is involving a problem of surface engineering. Otherwise when he deals with interacting surfaces in relative motion to improve the performance of a tribo-pair he is working in the field of tribology. Under such a situation he must consider the first axiom of tribology.

Lemma 2: The tribological property obtained under one system condition cannot be used simply in another system condition.

It is proved that the stiffness and damping coefficients of tilting-pad bearings measured in a test rig of inversed arrangement cannot be used in the application of direct arrangement.

For sets of samples of similar materials when ranging their tribological performance from data obtained in Timken machines, Amsler machines, Falax machines or SRV machines, the answers are different. Obviously for a target system there will be another answer.

Lemma 3: For any system including tribo-pair or tribo-pairs, it is a time variable system.

It can be divided into fast and slow for the variation. Some periodic behaviors with a period much shorter than system's life cycle the details of variation in the period needn't to be dealt with during investigation into the variation of system behavior in life cycle. They influence the pattern of variation of long period and the influences can be described by variable or invariable feature parameters in the life cycle. On the other hand during investigation into short period behavior to have the feature parameters of short period behavior for evaluating the influence on long period behavior the study in a small time scale is necessary. Meanwhile the long period behavior can be looked like time invariable condition.

Lemma 4: For a local part of materials on surfaces or between surfaces approaching end state (stable or equilibrium state) takes time.

When the period of interacting is small, there will be a transient process. This is one kind of time dependent.

For counter-form contact, either the local part of a surface or the lubricant is in a transient state in a long time after leaving the contact region due to that the time of passing through the contact region is usually very short and the interacting is different in different position.

It is the same situation for asperities and the medium surrounding the asperities.

Lemma 5: Study on the system state variation is a constituent part of tribology.

From the second axiom the lemma is obvious. In the history of friction, wear and lubrication only wear dealt with the long period state variation and a few study on lubrication dealt with the short period state variation. All of them considered only the simplest tribo-systems, i.e. a tribo-pair. It is far not enough. The study on state variation of large (or complex) systems considering the influences of each tribo-pair and each supporting sub-system is expected. Study on the systems engineering,

theoretical and methodological, is suggested as well [8].

Lemma 6: A condition monitoring sub-system is necessary and a condition compensation or control sub-system is suggested for the tribo-system [8].

A built-in test facility is suggested for all tribo-systems not only for alarming before catastrophic failure but also for collecting the data of pattern of time-variation of the system. Such data are very important to the study of tribology and life design of products of next generation.

Lemma 7: The attempt of using theories of any other individual discipline to modeling tribological behavior will not obtain correct result.

For example friction cannot be looked as only mechanical behavior even though it is treated as a mechanical phenomenon in the history.

Lemma 8: Observation on different geometric scale will obtain different result.

In a large-scale observation deformation forces (elastic and damping forces) and inertia forces are larger than the molecular forces between surfaces and between surfaces and lubricant while in a small-scale observation the situation is opposite. It comes from first axiom and second axiom. A typical example is elasto-hydrodynamic lubrication theory was foretold as a milestone of tribology in 20 century but no such an important influence for EHL has been found in the end of the century. One reason is that it oversees the lemma 8 (scale effect) in tribology and tries to use theories in macro-mechanics for isotropic and continuous medium in modeling behaviors of micro-scale.

4. EXAMPLES OF APPLICATION

Some works are doing now under the guide of the axioms in the Theory of Lubrication and Bearing Institute, Xi'an Jiaotong University:

4.1 Studies on the Railway Corrugation

Corrugation of the railway is a big problem especially for the vehicles of high speed. There is still no satisfactory explanation and model on the short wave length corrugation what can bridge the gap between theoretical analysis and practical observation. The coupling of dynamical and tribology behaviors has been paid much attention in this work. The dynamic system is analyzed at the first phase of study. The vehicle and track are represented by a lumped parameter system. The vehicle is with primary suspension while the rail-pad and ballast are modeled as distributed spring-damper elements. Hertz linear contact stiffness between wheel (connected to bogie) and track is taken into account. It is found that the distance of effect is different for the component of different frequency of vibration. For example the components in the neighborhood of 10 Hz affect the vehicle body and almost there is no influence on the track while components up to 400 Hz influence more severely on wheel and track, even on the condition of high speed and heavy haul. In the vibration spectrum the energy of components of high frequency absorbs by the material very near the contact point in the rail and wheel. They wear out the material on rail and wheel surfaces and make the corrugation. What we are doing is to calculate the relationship between the transmission distance and the frequency with a FEM model considering the elastic and plastic deformation and the shakedown limit under a vibration condition. It is believe that the short wave length corrugation is due to a large amount of energy from the vibration components of high frequency. It damages the surface layers of the rail and wheel. The results of the analysis and investigation will be reported later.

4.2 On the Piston-Ring Group-Cylinder Liner Systems [9][10][11]

In Fig.3 there are five items in consideration. (1) The efficiency of air filter and oil filter. They define the amount and size distribution of hard particles, which get into the piston-rings-cylinder pairs together with air and lubricant. (2) Sealing effect of rings preventing gas blow-by from the combustion cabinet. (3) Lubrication effect on the surfaces of rings, skirt and cylinder. It influences the friction loss and wear. (4) Wear of the ring surfaces and cylinder wall. Increasing ring gaps due to wear and then the blow-by increases. (5) A balance of applied forces, lubricant film force, asperity load etc defines the attitude of the piston. An analytical program that considers all of

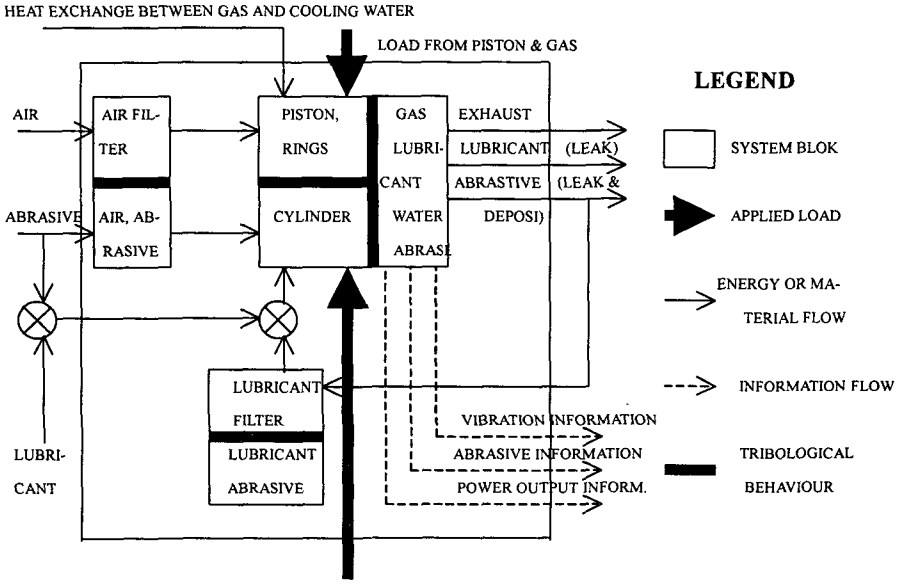

Fig 3. Block diagram of a piston-ring group-cylinder liner system

the five strong coupling behaviors in one model is available now, although some rough assumptions are made. For example, it is supposed that the debris with a size larger than the film thickness cannot enter the gap between two surfaces and the debris with a size less than the oil film thickness contribute nothing on the wear. Temperature distribution and thermal deformation together with force deformation of the piston skirt have been considered recently as well. A series of experiments were carried out to collect more information and check the models. An attempt of considering the influence of vibration of cylinder wall in multi-cylinder engines is carried out now.

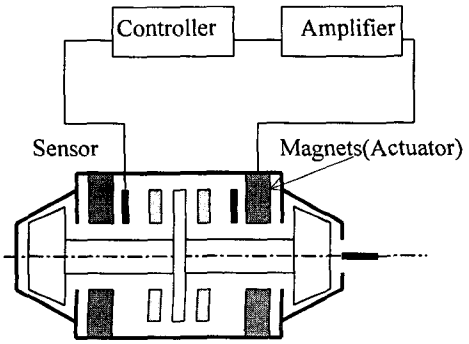

Fig.4 Active Magnetic Bearings in an Expander

4.3 On the active magnet bearings

It is worthwhile mentioning that the active magnetic bearing system (AMBS), which supports a given rotor, is a tribo-system with self-compensation (condition control) sub-system and with artificial intelligence

(Fig. 4) [12]. The design and manufacture of such a system involve multi-disciplinary knowledge and many technical areas. AMBS is referred to as a mechatronic product. The eddy current in the thrust disc induced by the magnetic field results a very high temperature and influences the work of the position transducers and then the controller. To avoid the contact of the rotor during electric power supply breakdown auxiliary bearings are usually used. In this case a thin film of self-lubrication polymer material is deposited on the surface of magnets instead of auxiliary bearings. It economies the space for a better layout and has a good performance during short time contact under very high speed (30,000 rpm). The coupling of behaviors becomes then more complex.

5. CONCLUSIONS

1. Lack of study of the concept system and method system is a severe problem for the development of tribology.
2. There are three axioms in tribology, which can be a foundation to establish the concept system and method system.
3. From the three axioms a series of lemmas can be deduced.
4. More theories deduced from the axioms and lemmas are expected.

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