TRIBOLOGY-BASED ENERGY EFFICIENCY

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ABSTRACT

Tribology is the science and technology of friction, wear and lubrication of interacting surfaces in relative motion. In almost every aspect of our daily lives some application of tribology can be met. Gripping, holding, sliding, brushing, machinery works, friction between skin and clothes, between wheel and road, etc. demonstrate the impact of tribology. This paper reviews literatures that report of what have been published about knowledge and ideas, on the tribology topic by accredited scholars and researchers, with respect to the efficiency of energy in its use. Results showed that by applying the science and technology of tribology the use of energy can be saved up to more less 11%.

Key words: tribology, energy efficiency, friction, wear, lubrication

ABSTRAK

Tribology adalah ilmu dan teknologi gesekan, keausan dan pelumasan pada permukaan yang saling berinteraksi dalam gerak realtif. Pada hampir setiap aspek kehidupan kita sehari-hari beberapa aplikasi tribologi dapat ditemui. Pencengkeraman, penggenggaman, peluncuran, menyikat gigi, permesinan, gesekan antara kulit dan pakaian, antara roda dan jalan, dll menunjukkan fenomena penerapan tribologi. Artikel ini meninjau pustaka-pustaka yang telah dipublikasikan tentang pengetahuan-pengetahuan dan ide-ide mengenai tribologi oleh para ahli dan peneliti, yang berhubungan dengan efisiensi energi dalam penggunaannya. Hasil penelitian menunjukkan bahwa dengan menerapkan ilmu pengetahuan dan teknologi tribologi, penggunaan energi dapat dihemat hingga kurang lebih 11%.

Kata kunci: tribologi, efisiensi energy, gesekan, keausan, pelumasan

1. INTRODUCTION

Due to the continuous worldwide depletion of natural resources, the prices of resources and energy production are increasing faster than those of the essential goods of life, such as foodstuffs. Moreover, the rate at which energy prices increase is expected to become much higher than that of other resources. Researches about how to improve efficiency in utilizing energy is underdeveloped. One of the largest consumers of energy is the manufacturing industry [1]. Energy-saving manufacturing technology will be more and more important. Furthermore, despite increasing energy prices, consumption will continue to expand rapidly in the near term as a result of expanding populations and substantial economic growth in developing countries. By 2030, as shown in Fig. 1, the global demand for energy will likely be about 30 % higher than it is today - even with substantial gains in efficiency. Therefore, energy-saving will be indispensable as an essential technology in the near future. In fact, much research [2-27] has already been initiated to develop energy-saving.

Tribology was defined in a DES Report in 1966 [29] which drew attention to the enormous financial losses due to machine breakdowns as a consequence of friction and wear in the UK. The report, known as the “Jost Report” after the committee chairman Dr. P. Jost, generated significant impact worldwide and similar reports, commissioned by other governments notably in the USA and Germany, confirmed the vast scale of the losses due to this problem. Later studies of this type showed that economic losses due to friction and wear remained significant, but that the sources of loss became more associated with the consumption of energy and materials rather than maintenance costs [30]. More recently it has become apparent that tribology also has the role to play in environmental protection, offering means to contribute to a reduction in the production of greenhouse gases and the sustainability of industrial products, reducing global warming and the impact of using non-renewable energy and raw materials [31]. It is generally believed that the economic losses to friction and wear are up to 4% of GNP in developed countries, about £8.5 bn for the UK in 2001, and that up to 1% of these losses can potentially be saved by the application of known techniques to reduce friction and wear in machines [32]. In this paper, literatures that report of what have been published about knowledge and ideas, on the tribology topic by accredited scholars and researchers, with respect to the efficiency of energy in its use is reviewed.

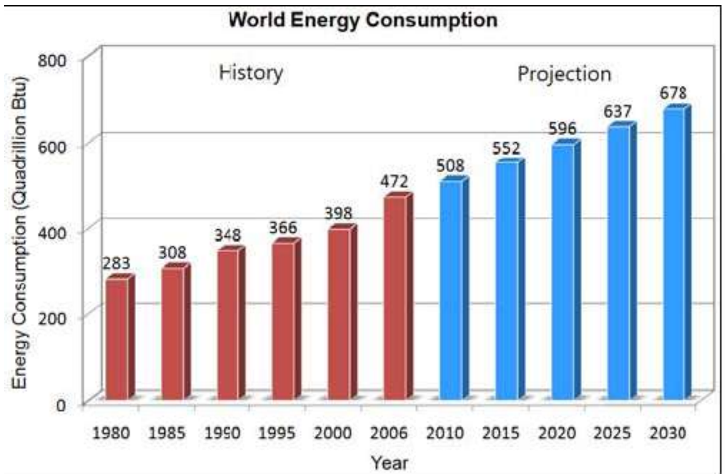

Figure 1: World Market Energy Consumption [28]

2. THE SCIENCE AND TECHNOLOGY OF TRIBOLOGY

Tribology is the science and technology of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. The study of tribology is commonly applied in bearing design but extends into almost all other aspects of modern technology, even to such unlikely areas as hair conditioners and cosmetics such as lipstick, powders and lipgloss. Any product where one material slides or rubs over another is affected by complex tribological interactions, whether lubricated like hip implants and other artificial prosthesis or unlubricated as in high temperature sliding wear in which conventional lubricants cannot be used but in which the formation of compacted oxide layer glazes have been observed to protect against wear. Tribology plays an important role in manufacturing. In metal-forming operations, friction increases tool wear and the power required to work a piece. This results in increased costs due to more frequent tool replacement, loss of tolerance as tool dimensions shift, and greater forces are required to shape a piece. A layer of lubricant which eliminates surface contact virtually eliminates tool wear and decreases needed power by one third [33].

Technologies have to fulfill functional engineering tasks. It is well known that in various technologies some basic engineering tasks can only be fulfilled through ‘interacting surfaces in relative motion’. A feature common to all processes of motion is the occurrence of effects of ‘resistance to motion’, that is, the occurrence of friction which may lead to friction-induced energy losses and wear-induced materials losses in tribological systems. Table 1 gives a brief simplified overview on technologies, their engineering tasks and examples of pertinent tribological systems [34]. The fulfillment of the engineering tasks exemplified in Table 1 requires an appropriate design and operation of tribological systems. For the operation of tribological systems the following groups of characteristics and parameters are of importance, as compiled in Figure 2: structure of the tribo-system, operational parameters, interaction parameters, and tribometric characteristics. From Figure 2 it is obvious that for a given tribo-system with defined structure and operational parameters the ‘interfacial interaction modes’ crucially influence the tribometric characteristics, that is, the friction and wear behavior of the system.

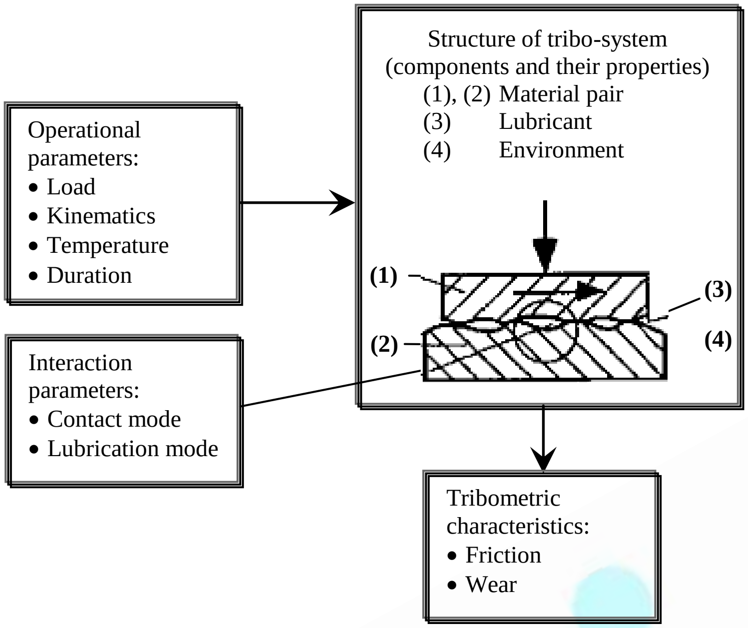

Figure 2: Basic groups of characteristics and parameters of tribo-systems [35]

When two surfaces are loaded for the first time and moved relatively to one another, changes in the condition of both surfaces generally occur. These changes are usually a combination of many things, such as the alignment of axes, shape changes, changes in surface roughness, and the equalizing of various mechanical and chemical properties between the moving surfaces, such as the micro-hardness, which is produced by selective work hardening or the formation of oxide layers and other boundary layers. All these changes are adjustments to minimize energy flow, whether mechanical or chemical, between the moving surfaces [36]. The changes which occur between start-up and steady state are associated with running-in (also called breaking-in or wearing-in, [37]). Although in terms of conservation, wear is always undesirable, running-in wear is encouraged rather than avoided.

Running-in occurs in the first period in the life-time of a rolling or sliding contact of a lubricated system, which is schematically shown in Fig. 3. Prior to running-in, the various pairs of contacting surfaces in, for instance, a new engine are not 'mated together'. There may be a slight initial misalignment and there will certainly be 'high spots' on all surfaces. Initially the clearances will be small and therefore the cooling flow or oil is low and this, together with the initial higher friction, leads to operating temperatures higher than normal. During the running-in period, the high spots left from the final machining process are reduced by plastic flow, voids are filled and overall shapes are matched. The higher temperatures usually cause higher wear rates, but as the surfaces become smoother and the more prominent asperities are flattened, the wear rate falls to a steady state. There are two dominant mechanisms in the running-in period; plastic deformation and mild wear [38]. The plastic deformation mechanism is similar to roller burnishing; the asperities literally get squashed down. The change of the surface topography can be the amplitude and/or the texture depending on the load and moving direction. Frictional losses usually decrease during this period and contact clearances increase, thus reducing the surface temperatures. The wear rate decreases until it reaches the normal steady-state wear rate for the design contact pairs. The wear rate during running-in, even when misalignments are minimal, is higher than during normal running.

After the running-in period, of which duration is invariably depending on the tribo-system, the full service conditions can be applied without any sudden increase in wear rate. The load carrying capacity reaches to its operating design. The steady low wear rate regime is maintained for the designed operational life. The term steady state is defined as the condition of a given tribo-system in which the average dynamic coefficient of friction, wear rate, and other specific parameters have reached and maintained a relatively constant level [39]. The wear rate may rise again once the operating time becomes sufficiently long for a

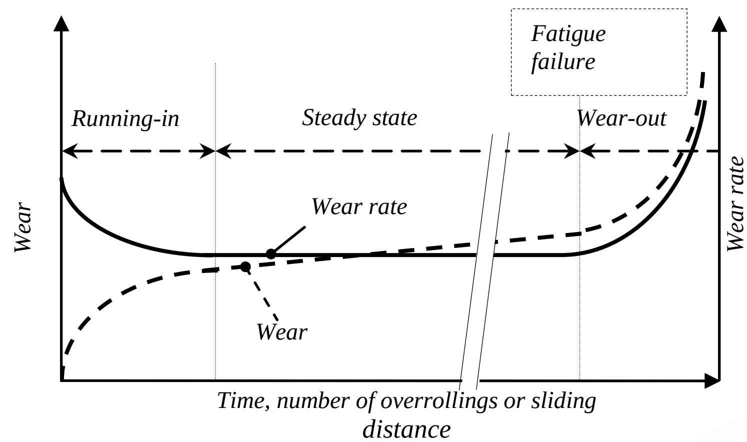

Figure 3: Schematic representation of the wear behavior as a function of time, number of overrollings or sliding distance of a contact under constant operating conditions

fatigue process to occur in the upper layers of the loaded surface. A significant contribution to material loss driven by cyclic loading is started. The particles from such a fatigue wear process are characteristically much larger than the small fragments associated with adhesive or abrasive wear [40]. This form of wear generates a 'pitted' surface (pitting failure). Once the wear particles due to fatigue wear accumulate the surface, it will wear-out i.e. total failure occurs. The running-in process is a complicated phenomenon related to surface texture, geometry, film formation, chemical and physical properties of materials in contact, lubricant or additives, operating conditions and so on and is not well understood yet. Jamari and Schipper [41] have reviewed the study of running-in. They found that most studies are based on experiments [42-58] in order to get an impression of the running-in behavior. Furthermore, the **initial surface topography** shows the most influencing factor with respect to running-in.

3. ECONOMICS ASPECTS OF TRIBOLOGY

The ASME study [59] estimates that tribology could potentially save the United States a total of some 11% of the national energy consumption, amounting to about $16 billion annually. It identifies road transportation as the sector which may potentially realize the greatest benefit, about 7.4% of the total US energy consumption, or $11 billion annually. The other potential energy savings include electric power generation (0.2% of total US energy consumption; $ 0.3 billion annually), turbomachinery (0.5%; $ 0.75 billion), and industrial machinery and processes (2.8%; $ 4.2 billion).

Furthermore, Ku [60] said that a direct energy saving of about 3.5% of the total US energy consumption can be expected from the road transportation sector, through reduced friction by using suitable low-viscosity engine and axle lubricants, and the use of more advanced multispeed transmissions to partially achieve the performance of CVT, and another 1.0% can be expected from the diversified industries through reduced friction and leakage losses. These direct energy savings amount to 4.5% of the total US energy consumption, or some $ 7.0 billion annually. A fairly conservative assumption can be made that the additional monetary benefits from improved machine reliability and life is 5 times the direct energy savings (compared with a factor of 12 in the UK analysis), then the total monetary savings from the near-term benefits can reasonably be taken as $40 billion annually. This is certainly significant by any standard, and does not include the long-term, less tangible items considered in the ASME study.

Prospect of surface modification for eco-tribology has been presented by Sasaki [61]. Multi-scale surface texturing is a new concept of surface modification for tribo-materials. Making use of the tribological phenomenon that becomes predominant at each scale level, multi-scale surface texturing aims at improving the total performance inclusively by architecting the surface structure on a consecutive scale from the nano-micro level to the macro level. Figure 4 shows a variety of surface structures and the processing related to the size of the texturing element and processing area. It starts from molecular modification on the surface using super molecules and self-assembled monolayers (SAMs), and there are various processing methods such as nanoparticle and/or multi-layer composite coatings, nano-imprinting, MEMS, sandblasting, laser ablation, precision machining and laser hardening. It will be very important in the future to create the multi-scale surface texture by combining two or more of these processing methods.

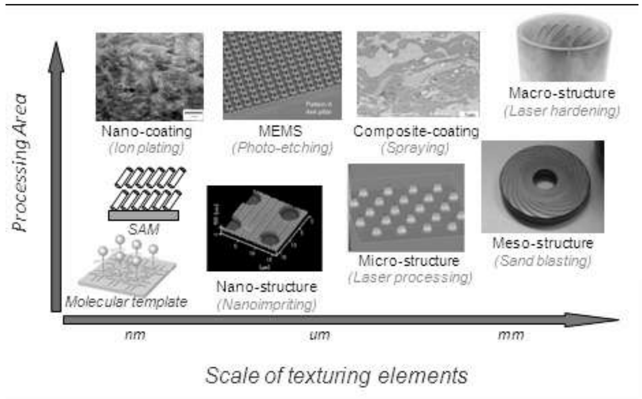

Figure 4: Variety of material processing for multi-scale surface texturing [61]

4. ENERGY EFFICIENCYTHROUGH TRIBOLOGY

Five ways in which tribology can contribute to energy efficient technology have been considered by Spikes [62]. First, develop low friction components by tackling the main problem caused by low viscosity lubricants – the thinning film process (see Table 1). Second and third, make new energy efficient technology work – traction drives and high temperature engines (see Table 2). In these cases, the introduction of these technologies depends, to a considerable extent, upon tribological innovation. Fourth, develop of methods of improving and better predicting rolling element bearing (see Table 3). The fruits of this can then applied to saving energy in two alternative ways, either by providing longer life bearings or by downsizing bearings and thus reducing friction. Fifth, simulate the engine, transmissions or other lubricated systems. This will be possible to optimize the energy efficiency of complex systems with several different tribological components.

Table 1: A few potential contributions of Tribology to the thinning film [62]

Area of Research	**Possible Benefit**
Mechanisms and modellng of mixed lubrication	Optimization of surface finish to limit friction throughout the mixed regime
Mechanisms of micropitting	Use of boundary additives to control micropitting
Mechanisms of wear in mixed lubrication	Antiwear additives which reduce both wear and friction over wide lambda value range
Mechanisms of boundary lubrication	Better friction modifiers able to function over longer periods
Improved surface finish and surface coatings technology	Modelling tools to predict effectiveness of surface finish and coating. Coatings designed to match lubricants or vice versa

Table 2: A few potential contributions of Tribology to the traction drives [62]

Area of Research	**Possible Benefit**
Molecular dynamics simulation of fluids in EHD conditions	Reliable models of fluid rheology in EHD Design of fluids with optimal rheological properties to give high EHD traction
Mapping friction in EHD contacts	Reliable models of fluid rheology in EHD
EHD solutions with realistic rheological Model and thermal treatment	Prediction of EHD traction based on measurable fluid properties

Table 3: Recent and possible contributions of Tribology to rolling element bearings [62]

Area of Research	**Possible Benefit**
Development of life models incorporating Fatigue limit for bearing steel	More accurate prediction of bearing life
Influence of roughness and contamination on life	More accurate prediction of bearing life. Filtration guidelines
EHD of rough surface and damage	Optimization of surface finish, including coatings
Grease lubrication mechanisms	Improved greases, better cage design, better predictive methods for life and friction
Mechanisms of crack growth and fatigue	Improved life prediction and bearing materials
EHD lubricant rheology	Reduced friction
Modelling bearing as dynamic systems	Improved design, life, friction

5. CLOSURE

Tribology is the science and technology of friction, wear and lubrication of interacting surfaces in relative motion. Some application of tribology can be met in almost every aspect of our daily lives. The published works about the significance of tribology to the energy efficiency have been reviewed. The term eco-tribology has been introduced for economically and environmentally friendly tribology. It has been showed that by applying the science and technology of tribology the use of energy can be saved up to 11%. Some methods for challenging the energy efficiency from tribological aspects were presented. This will give a new spectrum for tribological research in the future.

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