Modelling Aspects of Tribology: A Review

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Abstract: Modelling of tribology is an effective tool to predict the tribological behaviour of mechanical components (e.g., machine tools, cutting tools, piston, piston rings, liners, draw in, wire drawing, gears, etc.). Following a trend observed in all engineering fields, trobologists/tribological engineers recently started applying various modelling methods at various levels of sophistication to solve the tribological (friction, wear, lubrication) mechanism, effect of different parameters on tribological behaviour including prevention of these problems in a more accurate and efficient way. Modelling tribology is a challenge for the future and the tribologist are concerned about this need and playing a vital role by using computer codes.

This article led to a proposal for making the modelling of tribology which will give the better understanding for very simple tribo-systems. The aim of this technical note is also to attempt to provide some importance of tribology modelling as being looked from the theoretical aspects as well as the practical point of view.

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INTRODUCTION

Tribology represents a relatively new discipline embracing the topics of friction, wear and lubrication. It is a multi-disciplinary science in which engineers, metallurgists, mechanics, physicists, chemists, mathematicians and others are involved. Friction may be interpreted as a process of dissipation of energy, and wear as one of dissipation of a surface structure and/or mass.

Wear occurs in many different situations, e.g., on earth moving equipment, agricultural plough, slurry pumps, crushers, ball bearings, etc. Lubrication may be considered as a process by which the load between two solid bodies, moving relative to each other, is dissipated, with the dissipation of energy and mass concentrated more or less on the lubricant itself.

Older explanation of friction and wear behaviour have emphasised adhesive interactions of surface asperities [1]. For better understanding one should emphasise or focus on the plastic work in the near surface region, transfer phenomena and sequences, mechanical mixing of contact layers and the fracture of these layers. It is then possible to explain the size of friction coefficients, energy dissipated, flake-like and non-flake-like debris and microstructure effects. In dry friction problems and wear, tribologist can play an important part to introduce their understanding by using modelling [2]. At present, computer codes are applied by offering formulae chosen without discrimination. In low pressure lubrication efficient modelling has served to accurately describe the static and dynamic characteristics of bearings of various designs. But a better understanding of the problem is necessary and reasons for these variations must be found.

Due to the complex nature of tribo mechanism, a thorough understanding of the subject is still far off. The modelling approach can be a very useful tool as it provides engineers and scientists with a wide range of methods. Two approaches can be taken into account in developing models. One approach is based on empirical data which involves characterisation of surfaces, collection of tribological data in laboratory tests, correlation of data with field tests, and sorting of data. This approach is quite time-consuming and must be co-ordinated to be successful. A second approach involves generation of models based on known physical principles, followed by confirmation through data collection.

LITERATURE REVIEW

Due to the complexity of tribological processes, with or without lubrication, the modelling of tribology has long been appreciated. There are different routes to the modelling of tribology which basically depends upon the requirement. An author [3] proposed the route of modelling of wear in the following manner: if the primary need is for design information, relevant experimental data can be extracted from literatures or derived from experiments simulating the intended applications as closely as possible. These data are then fitted to empirical equations and extrapolated or interpolated as necessary following proper statistical procedures. Several simple wear models [4] yield wear equations of the Archard type, but they only considered the single material properties which is not sufficient. Some investigators [5, 6] have used the above approach and worked on brake materials and self-lubricated rolling-element bearings. Some other authors [7-9] studied mild, severe and abrasive wear model in which they described more fundamental approach. Their approach is to seek information on wear from experiments in which the variables involved have been identified and controlled. This approach is essentially a long-term one and tends to be open ended. It does, however, have the great advantage and lead to a gradually increasing level of understanding.

Low pressure lubrication model has been developed and served to accurately describe the static and the dynamic characteristics of bearings [10-12] of various designs and allowed the bearing to be looked upon as an integral part of the machine structure [13]. Common friction model was initiated by Kalker [14] and contact stress distribution during a tangential load cycle was monitored by others [15-18]. A model has been developed by Harnoy et al. [19] where they described the dynamic friction effects in lubricated surfaces which covered the hydrodynamic, mixed and boundary lubrication regimes. Formulae from early theories [20] are currently used in computer codes to calculate wear, wear rate and constant of proportionality, where the formulae suggest that the wear rate is proportional to the load divided by the material hardness. In order to pay full regard to all aspects of tribological models, in particular the machines, machinery or devices, modelling of wear under partial elastohydrodynamic lubrication conditions is also necessary. Jain and Bahadur [21] developed a model of fatigue where they considered that the normal stress responsible for wear was the stress acting at the surface. Later on, the same category of model was modified by others [22, 23] where they reported wear mechanisms and modelling of wear under partial elastohydrodynamic lubrication (PEHL). Some models have been proposed for the growth and removal of the oxide film during oxidational wear and also some sort of reviews have been given by others [24-26]. A model of abrasive wear in polymers is studied by Ratner et al. [27], where they suggested three consecutive stages involved in the detachment of a particle.

In veiw of all the theoretical as well as work report on modelling in the literautre, it can hardly be said that the modelling of tribology should be augmented to be able to predict the wear and friction phenomenon and give many benefits from many point of views, e.g., industrial efficiency, ecology, saving natural resources like petroleum.

TRIBOSYSTEM

Application of systems thinking or systems analysis can be very useful for describing and identifying the parameters of tribological processes. The tribo-system often takes the form of "model building" i.e., the representation of a system graphically in a manner which may permit the model to be used for a study of the systems performance. Systems analysis was effectively applied to tribology by Fleischer [28]. A system can be analysed in terms of its "structure" (elements, interrelations, properties) as well as in terms of its "function" (inputs, outputs, transfer functions). One practical aspect of a systems approach is that it readily leads to checklist of the parameters needed for the proper understanding of the phenomena. Another more theoretical aspect of the systems approach is that it can be used to relate to each other the various basic mechanisms in the complex processes of friction and wear. The purpose of technical system is the transformation and/or transmission of "inputs" into "outputs" which are used technologically [29]. Figure 1 shows a design model which indicate the functional description of tribological system in general. In design oriented models, the model should receive input on the one hand and produce output on the other hand. The relationship between a useful input and a useful output may be considered as the technical function of a tribosystem. Tribosystem that can be related to the four main groups of inputs or outputs are bearings and human joints (motion), gears and clutches (work), slurry pumps and crushers (materials) and cams and followers (information). Figure 2 shows the simplified form of a general tribosystem. The structure of the system is determined by the elements, their properties and the interaction between them. Usually the system consists of four basic elements viz., solid body, counter body, interface and surroundings.

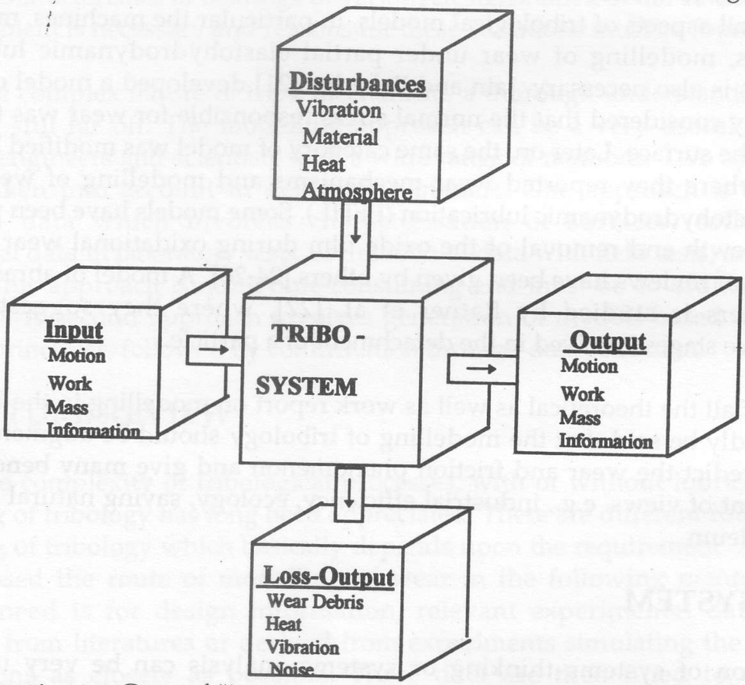

Fig. 1: General "input-output" description of tribosystems

MODELLING TRIBOLOGY IN BRIEF

The modelling approach can be a very useful tool as the approach provides engineers and scientists with a wide range of methods. Model should be based on known physical principles and should predict the performance of typical tribological contacts. Such models should have the capability of being used in design and material selection, and should be able to predict the value of friction co-efficient, wear rates, wear debris and the maximum life of components. It is important to characterise geometrically, chemically and structurally the surface and subsurface of each material in the system. The empirical approach of a model involves characterisation of surfaces, collection of tribological data in laboratory tests, correlation of data with field tests, and sorting out of data to build an empirical model. The following parameters should be kept in mind in approaching the empirical model.

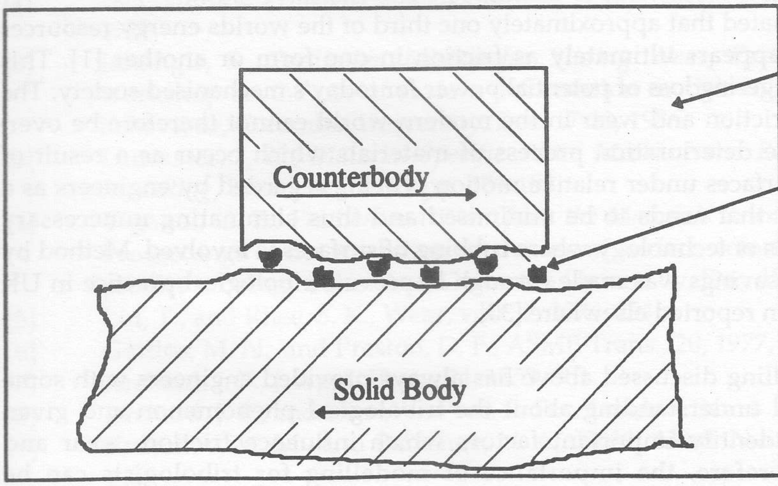

Fig. 2: Basic elements of tribosystem

A. Design Parameters

- Material systems: machine parts and lubricants
- Surface characteristics: surface roughness, effect of scuffing
- Loading characteristics: sliding, rolling
- Thermal characteristics: ambient, operating
- Geometric characteristics: piston/cylinder, cam/follower

B. Performance Parameters

- Service life
- High efficiency
- Service load
- Maintenance interval

Finally, the approach that are mentioned above are not unique, and can be changed. It should also be dynamic in the sense that one can update it easily with new parameters, correlation, etc.

For mathematical or numerical model, the works to be done include the derivation or formulation of different type of differential equations, solution of the equations by different numerical methods (e.g., Initial Value Problem, Boundary Value

Problem, Finite Element Method, etc.) and development of tribological model. The theoretical models must be checked and guided by experimental data to ensure the general applicability of the models.

IMPORTANCE OF MODELLING

It has been estimated that approximately one third of the worlds energy resources in present use appears ultimately as friction in one form or another [1]. This represents a staggering loss of potential power for today's mechanised society. The importance of friction and wear in the modern world cannot therefore be over-emphasised. The deterioration process of materials which occur as a result of interaction of surfaces under relative motion is being regarded by engineers as a damage process that needs to be minimised and thus eliminating unnecessary waste at all levels of technology where rubbing of surfaces is involved. Method by which financial savings was made through improved tribological practice in UK industry has been reported elsewhere [30].

Tribology modelling discussed above has always provided engineers with some information and understanding about the tribological phenomenon and given advantages to identify important factors which influence friction, wear and lubrication. Therefore, the importance of modelling for tribologists can be considered as a significant one for more effective approach of understanding the problems of tribological behaviour in tribo-systems. Actually, computer modelling can give accurate predictions with accurate geometrical and other input parameters.

According to engineering practice, many models have been simplified to obtain practicable solutions. Frequently, the results of simpler models can be applied much more easily to practical problems than those of theoretically more precise but much more complicated, containing ill-defined or unknown factors.

CONCLUDING REMAKRS

A very high priority recommendation is being made for the modelling of tribological systems. The success of tribology model is essentially in the incorporation of physical and chemical processes which occur at the interface.

However, with some assumptions the technique of modelling approach which has been made will give a grim understanding of the prediction of the phenomena.

Here, we briefly mentioned the modelling aspects of tribology in general, that is, an approach towards a coherent description of tribology model. Future attention should be paid to discuss elaborately with emphasis on micro-models and macro-models including chemical and mechanical models.

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