Design of Tribosystem

⇒ The tribological design of machine elements: Introduction

→ It was evident as per the history of Tribology that many important tribological concepts and theories were stimulated by the need of new machinery developments and the new tribological research findings, in turn, have helped to upgrade the design of more efficient and more reliable tribological elements.

→ Then one can divert the attention to the tribological design process of generic elements and its applications to determine tribological performance of machine elements, and to the needs in improving this design process to meet the requirements of future machineries in aerospace, automotive, and information processing industries.

→ As new technologies emerge in aerospace, energy, manufacturing and communication industries, machineries are required to operate under much higher temperature with higher efficiency and reliability. These requirements presents new challenges in research and design of tribological elements to discover new lubrication concepts, new materials, new surface modification techniques, and new predictive theories to develop the advanced machineries.

⇒ Historical Developments

→ In tribological design, one should mostly concerned with two basic elements, the conformal sliding bearings and counterformal rolling and sliding contacts.

→ Tribological design of rolling and sliding contacts has been evolved mostly from the needs of better rolling element bearings and gears in machinery developments.

→ Tribological design of very low speed and heavily loaded sliding contacts depends on the protection of boundary films.

⇒ TRIBOLOGICAL DESIGN PROCESS

→ There are two types of elements in tribological design. The first type is simple generic elements involving either conformal sliding surfaces or the counterformal rolling and sliding contacts as shown in fig.1.

→ The second type is tribological machine elements which include all bearings, gears, cams and other rolling and sliding components. A brief discription is given to the tribological design process for each of these two types of triboelements

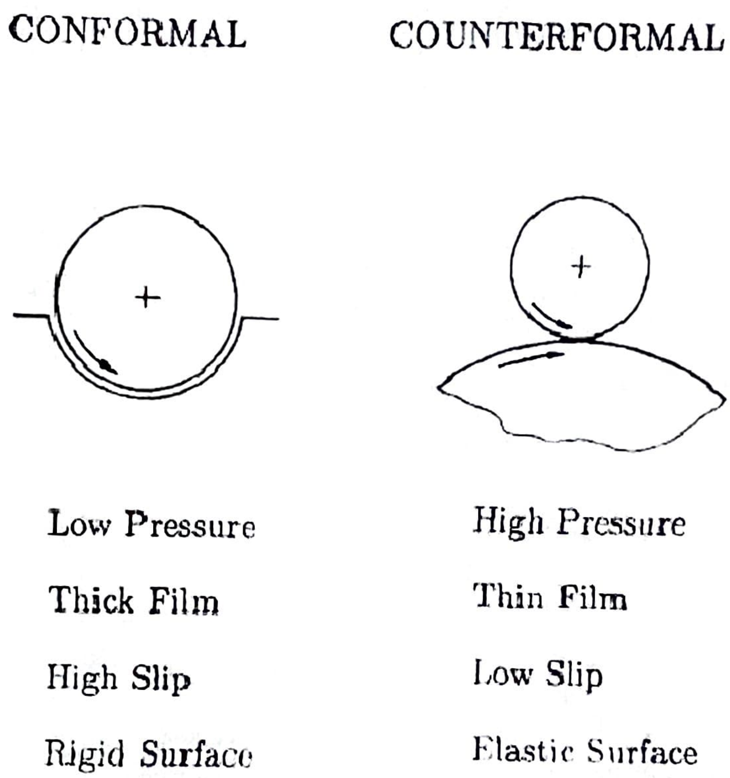

fig.1. Generic Tribo-Elements

1. Generic Tribo-Elements

The processes for designing a generic triboelement, as illustrated in fig.2, begin with the input data, which may be arranged in the following five groups:

a. Geometrical Data, such as the principal radii of the contacts,
b. Roughness Data, such as the average roughness height, average asperity radii, etc.
c. Operating Conditions such as range of load, speed, temperature, etc

d. Lubricant Properties, such as viscosity, shear modulus, limiting shear stress, thermal conductivity, etc.

e. Materials properties of solids, such as elastic and shear modulus, thermal conductivities, specific heat, yielding stress, fracture toughness, hardness etc.

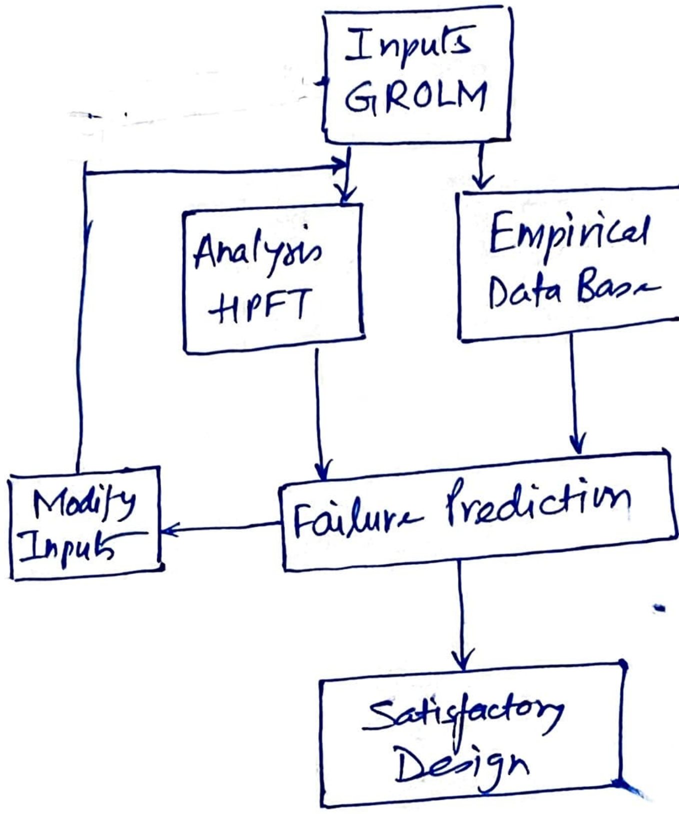

Fig. 2 Design Process for a Generic Tribo-Element

→ One may use a subroutine named "GROLM" to identify the five major groups of input data needed to initiate the tribological design process.

→ Since, most of these input data is entered manually in the computer programs for tribological design.

→ This inefficient method of handling the input data can be improved if the lubricant and material database is computerized and interfaced directly with the tribo-design program.

→ The second step in the design process is to determine the tribological performance described by:

1. The film thickness, H; 2. The contact pressure, P; 3 The friction force, F and 4. The contact temperature, T

→ A subroutine named "HPFT" may be used to identify the calculation of these tribological performance variables which are used to determine whether the element would fail under the given operating conditions.

→ For contacts operating in thick film lubrication, the distributions of film lubrication, the distributions of film thickness, pressure, friction and temperature can be predicted by theories ignoring the surface roughness effects.

→ For contacts operating in thin film lubrication, the sliding asperities are no longer separated by a thick oil film. They are protected by a very thin oil film or by a surface film.

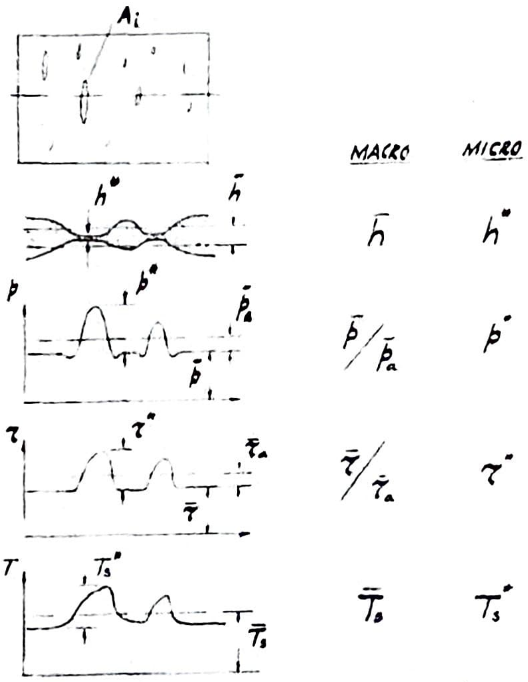

Fig. 3 Average and Micro-Contact Variables in Thin-Film Lubrication

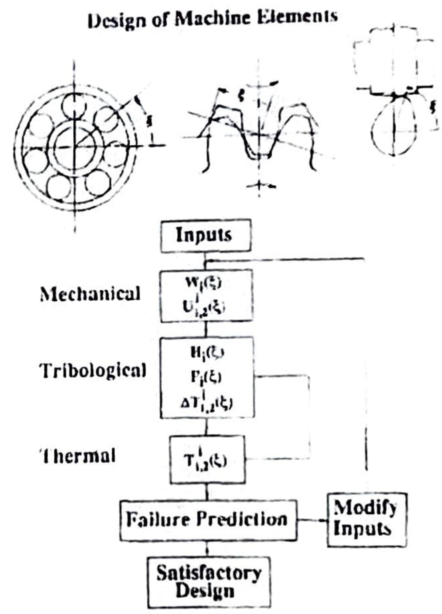

Fig. 4. Block Diagram for Design of Tribological Machine Elements

→ Tribological performance in the thin film regime, as represented by average quantities of the film thickness, lubricant and asperity pressure, lubricant and asperity shear stress, and surface temperature, $\bar{h}, \bar{p}, \bar{p}_a, \bar{\tau}, \bar{\tau}_a, \bar{T}_s$ shown in Fig. 3 may not be sufficient to predict tribological failure.

→ There is a need to extend the tribological performance to include the characteristics of these quantities at the asperity level considering each asperity as a micro-contact. These micro-quantities are labelled as asperity film thickness, contact pressure, shear stress and surface temperature, h^*, p^*, τ^*, T_s^* as shown in Fig. 3.

→ The relation of these performance variables with the major tribological failures such as contact fatigue, scuffing and wear are not fully understood. They are yet to be identified and quantified.

→ The most important step in tribological design is failure prediction. Ideally, failure predictions should be based on analytical failure models which relate a major failure mode to certain critical tribological variables, such as the relation between contact fatigue life and a critical maximum Hertzian pressure, and the relation between scuffing and a critical total contact temperature.

→ Unfortunately, analytical predictions of sliding failures based on calculating tribological performance variables in the thin-film regime are not always accurate and reliable. One cannot predict analytically the tribological failures. This most critical block is also the weakest link in the tribological design process.

→ In the case there are no accurate analytical failure models available, alternative methods, based entirely or partially on failure database obtained experimentally may be used.

⇒ Tribological Machine Elements

→ Fig. 4 shows a block diagram illustrating typical steps for designing a machine element, such as rolling bearings, gears and cams. As shown in figures, each of the elements may contain many generic tribo-elements like EHL contacts which may be interact dynamically and thermally.

→ The design process begins with entering all the geometrical, roughness, operating, lubricant, and material property data as discussed earlier for the generic elements.

→ The first step is to determine the cyclic dynamic loads on all the interacting generic elements. In this block the symbol $W_i(\xi)$ denotes the dynamic load for the ith contact; ξ denotes a space coordinates tracing the contacting path; and $U^i_{1,2}(\xi)$ denotes the surface velocities of the ith contact.

→ The tribological performance together with the bulk surface temperature $T^i_{1,2}(\xi)$ are determined for all the interacting elements simultaneously by an interactive process.

→ The calculated tribological performance is used to predict failure for each element. A satisfactory design is obtained if no tribological failure is found for all tribo-elements.

→ The weakest link in this design process as discussed, is the lack of reliable analytical failure prediction tools for the tribo-elements

→ A second weak link in this process is the calculation of the bulk surface temperatures $T^i_{1,2}(\xi)$.

→ The reliability of these predictions is dependent on how close one can predict the surface convective coefficients around all tribo-elements.

→ A slight error in the ~~blood~~ bulk surface temperature predictions can lead to considerable uncertainties in tribological failure calculations.

⇒ Current Needs

→ In reviewing the tribological design processes, one can identify a number of weak areas where continuous research is needed to improve the design process. These include:

1. Prediction of Tribological performance in Thin film lubrication
2. Analytical Models of contact fatigue Life.
3. Modelling of scuffing failure
4. Wear modelling in Lubricated contacts.
5. Prediction of Bulk surface
6. Computerized Tribological Design systems.

1. Prediction of Tribological Performance in Thin film lubrication

→ In thin-film lubrication, the tribological failure is likely controlled by events at the asperity contacts. The distributions of asperity lubricant film thickness, pressure, temperature, and shear stress are pertinent information for establishing failure criteria in this regime.

→ These quantities are, of course, dependent upon the surface roughness topography represented by a set of parameters such as average height, asperity radius, skewness, etc

2. Analytical Modelling of Contact Fatigue

→ In the past three decades, life prediction in lubricated contacts has relied heavily on the Lundberg-Palmgren formula derived from a set of extensive bearing life tests relating the maximum orthogonal shear stress and stress volume to life.

→ Fig. 5 shows the predicted trend of increasing fatigue life with increasing Λ, the ratio of lubricant film thickness to surface roughness. It agrees well with those observed in bearing life tests.

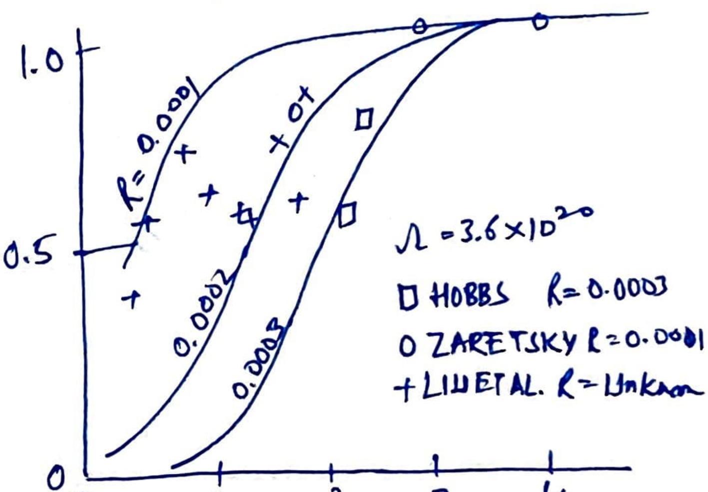

Fig. 5. Predicted Trend of Increasing Fatigue Life with Increasing Λ

→ An alternative model to L-P's relation for contact fatigue life was developed by Tallian, Chiu and Van Amerongen. Their model is considerably more sophisticated than L-P's model, and includes not only the materials strength effect and Hertzian stresses but other effects like defect shape, defect density, asperity contact stresses and traction due to shearing the lubricant and the asperity junction.

→ Trends similar to that shown in Fig. 6 for the EHL effects can also be predicted from Tallian's theory.

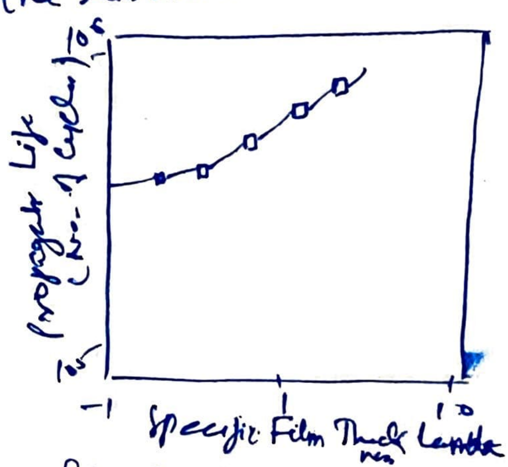

Fig. 6. Analytical Predict...

→ While the Lundberg-Palmgren's empirical relation has proven to be a practical tool for life prediction of rolling bearings, it is not an analytical model based on the basic principles governing the fatigue crack growth in contacting solids.

→ Contact fatigue modelling based on basic relations controlling initiation and propagation of surface and subsurface cracks appears to be more satisfying and rational approach, and should accomodate more easily the effects like lubrications, asperity stress, friction and materials imperfections.

→ It also appears the status of contact fatigue life prediction is still heavily dependent on empirical methods originated from Lundberg and Palmgren.

→ Analytical models based on understanding of crack propagation yield results encouraging, but are insufficient for accurate life prediction because of the exclusion of initiation life. Continous efforts are needed for developing a complete model for contact fatigue life including both initiation and propagation life.

⇒ 3. Modelling of Scuffing failure

→ For lubricated contacts operating at a high slide to roll ratio, the load can be limited by scuffing which is characterized by a sudden transition from low to very high wear rate accompanied by metal transfer.

→ Because of a lack of adequate understanding of the lubrication breakdown mechanism causing scuffing failure, analytical predictions of the threshold of scuffing have not been entirely satisfactory.

→ Future succes in this area appears to depend on continuous efforts in understanding the breakdown of the following two types of films in protecting the sliding asperities.

⇒ 4. Wear Modelling in Lubricated Contacts

→ Reliability prediction of tribo-systems would be much easier if designer can accurately predict and control wear in lubricated contacts. Unfortunately, such wear predictions are not possible at the present time because of a lack of good wear models in the lubricated regime.

→ Wear behaviour in dry and lubricated contacts is so complex that a general predictive model appears to be a nearly impossible task. However, a restrictive model, based on a limited number of simulative wear tests, may be successful in predicting wear within a range of operating conditions.

→ Much of the past modelling efforts in lubricated wear seems to follow this approach. For example, modified the Archard's wear model for dry wear developed a relation for wear in boundary lubrication constants to be derived from wear experiments.

→ It appears that Rowe's model may be extended to include the effect of EHL in reducing the ~~wear~~ wear at the asperity contacts. ~~This~~ and effects of micro-EHL in reducing the wear at the asperity contacts. This seemingly simple approach might be a useful first step towards developing an adequate wear model in lubricated contacts.

⇒ 5. Prediction of Bulk Surface Temperature

→ The significance of bulk temperature in determining the tribological performance has been well recognized by designers. However, there still is a lack of an effective method in handling this problem, other than the cumbersome and costly finite element method.

→ With the current trends towards developing integrated computer softwares for prediction of tribological performance, it appears to be ripe to develop a versatile computational tool to determine the bulk temperatures of a system of interactive tribo-elements using Blok's thermal network concept.

→ Of course, the thermal resistance for each tribo-element within the network can still be determined beforehand by the finite element codes and enter in the network as numeric database.

⇒ 6. Computerized Tribology Information System

→ In carrying out a tribological design process as shown in fig. I. it is often difficult to locate the pertinent numeric database for the lubricant and material properties, the appropriate softwares for calculating the tribological performance, and the pertinent criteria for predicting the failure thresholds.

→ Often designers find themselves spending so much time in searching such information and still end up with not quite the most desirable data or method.

→ This problem can be alleviated if a centralized and computerized tribological information system can be developed. Such need has been pointed out by several countries and action are now underway to develop such systems for designers.

→ An example of this is ACTIS, known as a computerized tribological information system currently being developed by the National Institute of Standards and Technology with support from the U.S. Department of Energy.

→ As shown in fig. 7, AICTIS will has six databases with the numeric and design database aiming directly to tribological design and other databases to assist in production and research.

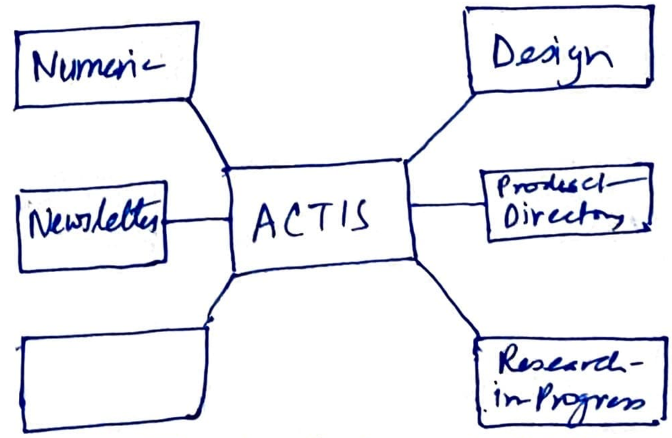

fig. 7. The Six Database in AICTIS

⇒ New Challenges

→ In the past, tribological design has centered mainly around metallic pairs lubricated by mineral or synthetic fluids. This situation is changing rapidly due to needs in developing high efficiency and light weight automotive and aircraft engines, precision manufacturing machines, and information processing equipments.

→ ~~New~~ Numerous unconventional materials, lubricants, and lubrication concepts have emerged as promising candidates to meet these new needs.

→ Yet, there is very little analytical understanding to guide the design of these tribological applications.

1. Mechanics of soft films
2. Mechanics of Hard Coatings
3. Lubrication and Wear of cermics
4. Mechanics of super Thin Oil film