Department	**Mechanical**		**Program**	**M.Tech**		
Subject Name	**Design of Tribosystems**		**Subject Code**	**MSD 301**		
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Unit I

Topic Name: Application of system concept to tribology, Function of Tribo mechanical systems, Structure of Tribo mechanical Systems, Tribological interaction, Function plane, mechanical work plane, thermal plane and material plane.

Links to the Resources:

1. ***https://books.google.co.in/books?id=QQKKv3lHCgEC&pg=PA24&dq=application+of+system+concepts+to+tribology***

Lecture Notes:

Lecture 1:

1. INTRODUCTION

The problem of dealing with complex multidisciplinary subjects like tribology appears to be essentially one of the limitations of "analytical procedures" in science and technology. The theoretical bio physicist Ludwig Von Bertalanffy, the founder of "General Systems Theory", has given the following definition of meaning of analytical procedure. An entity; i.e., the object of an investigation, should be resolved into the parts from which it is combined; hence it could be constituted or reconstituted from the same Parts. These procedures should be understood both in their material and conceptual sense. This basic principle of "classical "science can be applied analytically in a variety of directions, e.g., resolution of causal relations in to separate parts, searching for "atomic units" in science or for "material constants" in engineering.
Application of the analytical procedure to any of these areas depends on two conditions:

1. The interactions between Parts must be non-existent or, at least, weak enough to be neglected for certain research purposes. Only under these conditions can the Parts be first singled out actually, logically, and mathematically, and then reassembled.
2. The relation describing the behavior of parts must be linear, only then is the condition of summativity given, i.e. , an equation describing the behavior of the Whole has the same form as the equations describing the behavior of the parts; partial processes can then be superimposed to obtain the total process, and so on

These conditions are not met in the entities called systems, they consist of "parts in interaction". A system of "organized complexity" may be circumscribed as one in which strong inter actions, which are"non-trivial", i.e., non-linear, prevail. To deal with complex, non-linear systems, additional restraining principles have to be introduced. The economist Kenneth Boulding has suggested a hierarchy of systems based on the following three rules:
(1) Systems belong to classes of different levels of complexity.

(2) All logical and empirical laws, validate a low level (system) are also applicable to any of the higher level systems.
(3) The higher the level, the larger the number of unknown elements and undiscovered laws that make a particular system work.
To illustrate the system concept and the principle of the hierarchical order of systems consider, for example, a traffic system shown schematically in Figure 1.
Depending on the location of a so-called "systems envelope", separating hypothetically the subjects under consideration from their "environment", different levels of complexity or different "ranks" of the system under consideration can be distinguished. The systems of the lowest rank are in general given by the elementary single technical components. (If these elementary parts of technical systems are resolved further, the micro-physical and chemical constituents of the technical systems components are obtained.) Technical systems of the next rank up are obtained in putting together systems of a lower rank by certain technical means or through interactions of lower ranking systems.

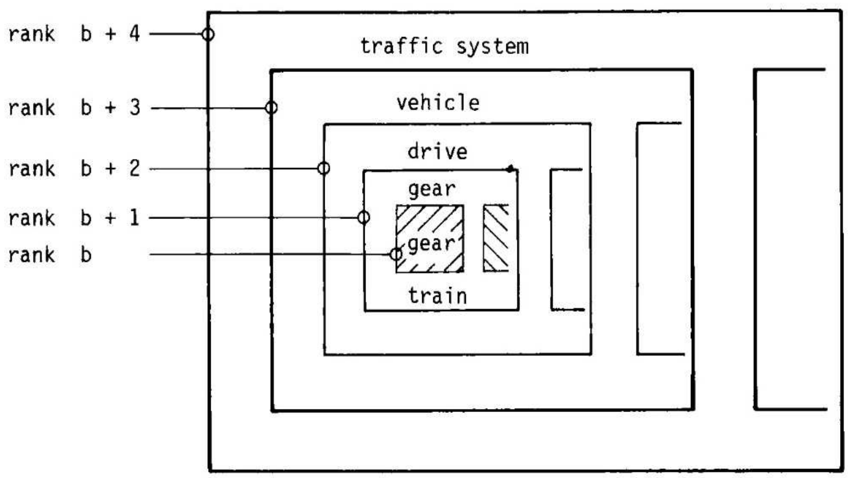

Figure 1: Example of a hierarchy of systems.

In the example shown in Figure 1, the elements of lower rank, denoted by the symbol "b", are, for instance, technical components like gears, shafts, etc. Through the dynamic interactions of these components, a gear train system of rank b +1 is formed. This system together with other systems of the rank b+1 (i.e., the engine system, the clutch system and the power transmission system) form a system of rank b+2, the drive system. At the next rank up, b+3, characterizing the whole vehicle, the top most level of this technical system is reached. At the following level b+ 4 man-machine interactions must be taken into consideration. Infact, the whole traffic system of rank b +4 results through dynamic interactions of vehicle + driver + road + atmospheric conditions.

2. DESCRIPTION OF A SYSTEM

The general definition of a system is contained in the sentence:
"A system is a set of elements interconnected by structure and function"
A system is termed open when interchanges of mass and energy with the "outer world" occur, while such interchanges are assumed to be negligible in a "closed" system. In the first case, for example, the transformation of kinetic energy into heat or other forms of energy through irreversible processes leads to "dissipative

systems". The main characteristics of a system are summarized in Figure 2 the symbols used have the following meaning.

(I) Structure

The structure of a system is defined by

(a) The set of its elements (A),

(b) The relevant properties of the elements (P),

(c) The coupling of elements, specified as relations between the elements (R)

With these definitions the structure of a system is represented by the set:

$$S = \{A, P, R\}$$

(II) Inputs, Outputs

Each system can be separated schematically by a hypothetical system envelope (or control surface) from its "environment". The connections between the system and its environment, which are cut by the envelope may be classified as:

(a) Inputs {X} and

(b) Outputs {Y}

(III) Function

The function *of* a system-utilized for a certain (technical) purpose – is to transform the inputs {X} into the outputs **{**Y**}.** The transformation (T) of the inputs into the outputs may be described either in terms of mathematical equations or as a physical analog, or as a verbal description, etc.

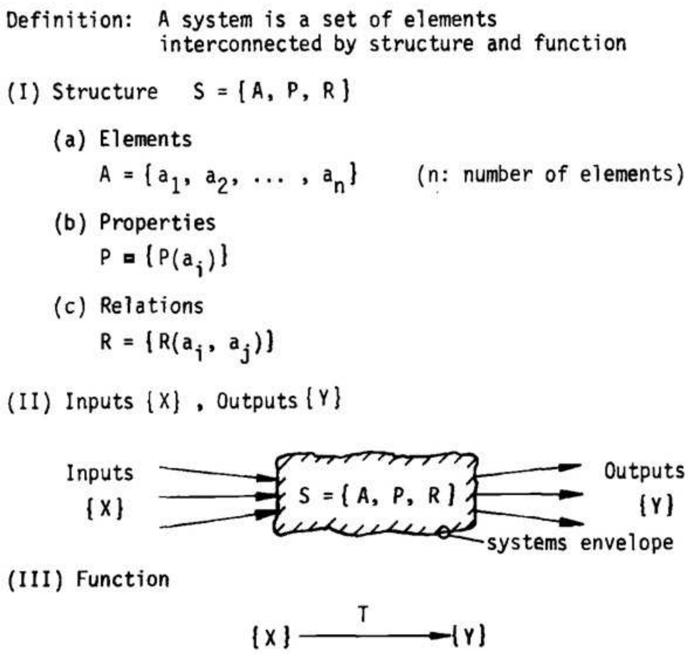

Figure 2: General Description of a System

For the characterization of the function of a system, mainly three different methods may be distinguished

(a) Dynamic State, Differential Equations

If the inputs and outputs vary with time, the system is said to be in a "dynamic state". This dynamic state may be represented by a set of differential equations, named "equations of motion".

(b) Steady State, Linearity

In certain cases a system may be in dynamic equilibrium, i.e., "steady state". Further, the outputs {Y**}** can often be described as linear superposition of the inputs {X} I through an algebraic representation.

(c) Stochastic Processes, "Noise"

In real systems the functional input-output-relations may be influenced by stochastic processes, i.e., dynamic effects of uncertainty and random disturbances, "noise". In such cases, an estimate of the limits of proper function behavior by means of the theory of probabilities can be attempted.

In describing the behavior of a system by the terms "structure" and "function" a fundamental difference should be noted:

A "structural" description of a system is essentially an "internal" one, viz., an attempt to understand the system's behavior in terms of its elements (the parts) and their interdependence.

A "functional" description of a system is "external", characterizing the system's behavior by its interactions with the environment through its input-output relations.

3. APPLICATION OF SYSTEM CONCEPTS TO TRIBOLOGY

The review of the system concept given shows that a system should be analyzed in terms of its "structure" (elements, properties of elements, inter relations between elements) as well as in terms of its "function" (inputs, outputs, transfer functions). In developing further the methods of the application of the system concept to tribology. We will attempt in the following to outline a simplified general theory of tribology.

The systems approach to tribology is not intended to replace more traditional analyses **of** friction and wear processes. Much of the information required for the portrayal of tribological phenomena from a systems stand point can be obtained through conventional procedures of analysis. For instance, important variables such as force, velocity, temperature, chemical, potential and the related variables stress, strain, work, power, heat flow and reaction rates can only be determined by standard methods. In the application of system analytical methods to ascertain complex subject, systems analysis of then takes the form of "model building", i.e., the representation of a system graphically or analytically in a manner which may permit the model to be used for a mathematical study of the systems performance. This is not intended here, nor generally possible at the present level of our understanding of the tribology of mechanical systems. The purpose of this is the development of a logical system analytical framework, whereby current tribological knowledge can be better organized, taking into account the various aspects and influencing factors. In this general theory, a detailed mathematical analysis is not necessary for a discussion of the pertinent basic concepts. Thus, in the following, systems thinking is applied rather than a formal systems analysis .In attempting to apply the system concept to the subject of tribology, a fundamental difference between the behavior and the description of electrical systems and mechanical systems in which friction and wear processes occur must first be emphasized.

Consider, for example, an electrical transformer and a mechanical gear box, illustrated in Figure 3 as block diagrams. The technical design of both systems is to transform certain inputs-voltage U and current I in the electrical system and angular velocity W and torque M in the mechanical system respectively- into outputs used for the technical purposes. The technical function of both systems can be described formally as a transformation of the inputs into the outputs via a certain transfer function (T).

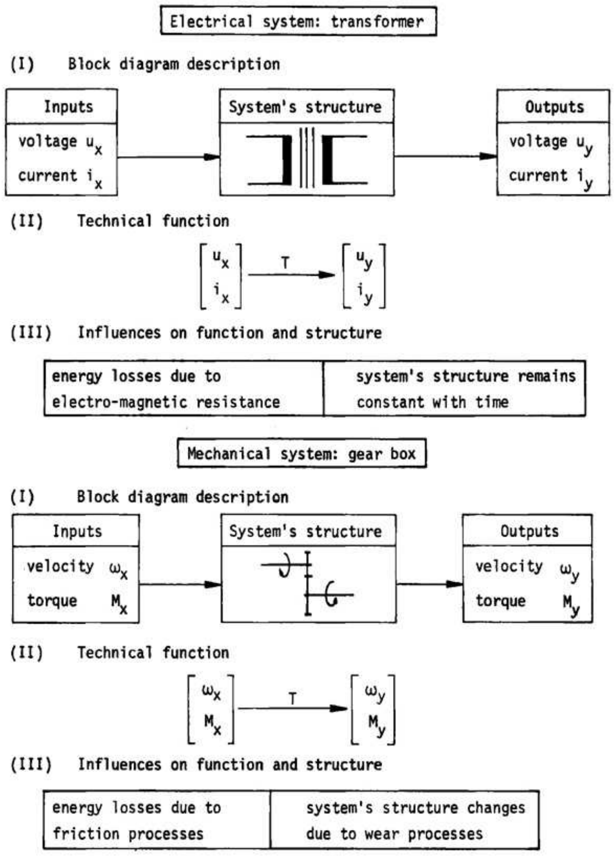

Figure 3: Comparison of the characteristics of an electrical and a mechanical system.

The dynamic performance of both systems is accompanied by perturbations on their function and structure. In both systems, energy losses due to electro-magnetic or friction resistances, respectively, occur. The fundamental difference between the behavior of the electrical and mechanical systems is that in the electrical case the structure of the system generally remains constant with time. In this case, the transfer function (T) can be worked out mathematically. This has led to various applications of the powerful systems engineering methods of network theory and related methods characterizing the functional behavior of electrical systems or related models. In the mechanical case, however, the structure of the system generally changes with time through the action of the tribological processes of friction and wear. Therefore, for mechanical systems a systems description in mere terms of input-output relations is not sufficient: the functional description of the system must be supplemented by a detailed study of the structure of the system and the influences of tribo- induced structural changes on the functional behavior of the system.

In order to develop a convenient framework for the description of systems with both a dynamic functional behavior and a dynamic structure state, some simplifications must be introduced: a first simplification should be made by applying the methods of "black-box cutting " or "systems tearing "Black-box cutting has worked exceedingly well in physics and chemistry: a model is cut down to smaller boxes until first principles can be applied. Systems tearing can be achieved by locating the hypothetical systems envelope in a convenient manner. In the following treatment the systems envelope is located, as narrow as possible, around the central parts of the mechanical system, forming the well-known “inter acting surfaces in relative motion". With these reservations in mind, a detailed systems description must involve the following steps:

(I) System's function

(i) Separate the system from its environment by the choice *of* a System’s envelope,

(ii) Compile all inputs and outputs
(iii) Describe the functional input-output relations
(II) System's structure
   (i) Identify the “elements” of the system
   (ii) Characterize the inter relations and interactions between the elements,
   (iii)Specify the relevant properties of the elements

Lecture 2

4. FUNCTION OF TRIBO MECHANICAL SYSTEM

In the attempt to apply the system concept to the phenomena of friction, lubrication and wear, the question of the functional, technical purpose of the system under consideration has first to be answered. A tribo-mechanical system is defined as an entity whose functional behavior is connected with interacting surfaces in relative motion. (The words "tribological system” or "tribo-system" may be used synonymously to the word "tribo-mechanical system") The technical aims realized through moving surfaces may range from aerospace applications to biomechanical joints. However, from a physical point of view, four basically different groups of technical purposes can be distinguished as illustrated by the examples shown in Figure 4.
The most general technical purpose o f a tribo-mechanical system is the realization of motion through various types of "bearings". The other basic groups are the transmission of mechanical work, the transmission of information - for instance the control of machine functions with cams- and the forming of materials. As a supplement to the basic classification of tribo-mechanical systems into four different groups, illustrated in Figure 4.

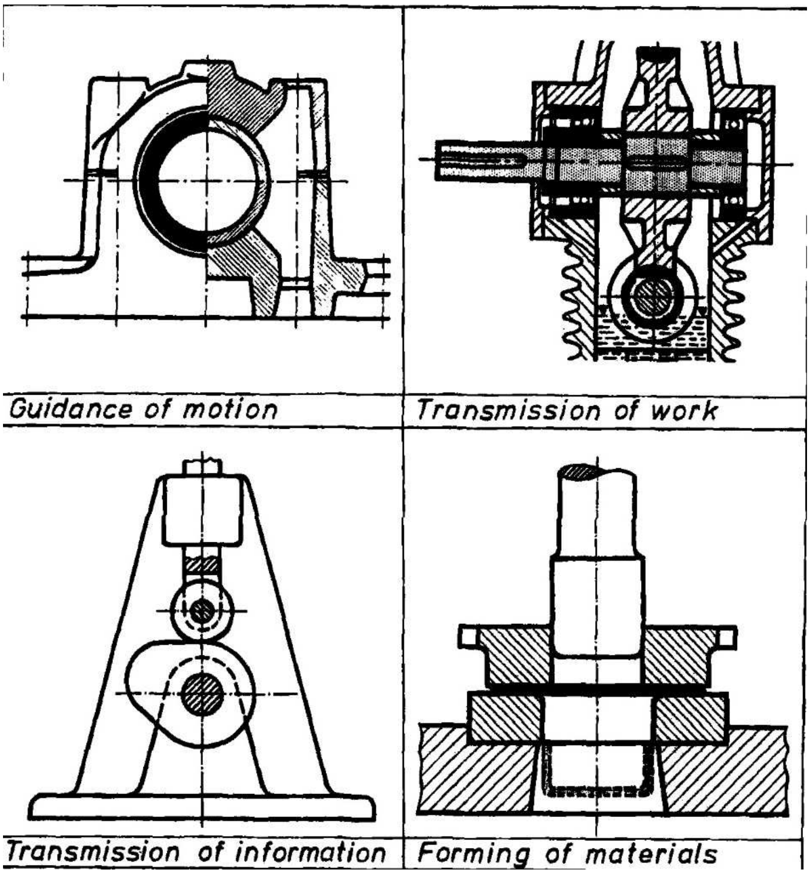

Figure 4: Types of tribo-mechanical systems

In an abstract and highly simplified description, the function of the different tribo-mechanical systems consists, basically, in converting the inputs - for instance, motion, mechanical energy and materials – into outputs, which are used technically, the functional cause-and-effect relations between inputs and outputs are accompanied by loss-outputs of mechanical energy and of materials, denoted summarily by the terms friction and wear losses. From a point of view external to the system, the system may be treated as a black-box with inputs and outputs, as shown schematically in Figure 5.

The technical function can often be expressed as a relationship between an input and a useful output. Not all the inputs may be considered desirable, some may be regarded as disturbances. Not all the outputs may be desired: such outputs may, from the practical point of view, be considered as losses. In general, part of a functional input may be lost, appearing as a loss output. However, the loss output need not be quite the same type of quantity **as** the input or useful outputs.

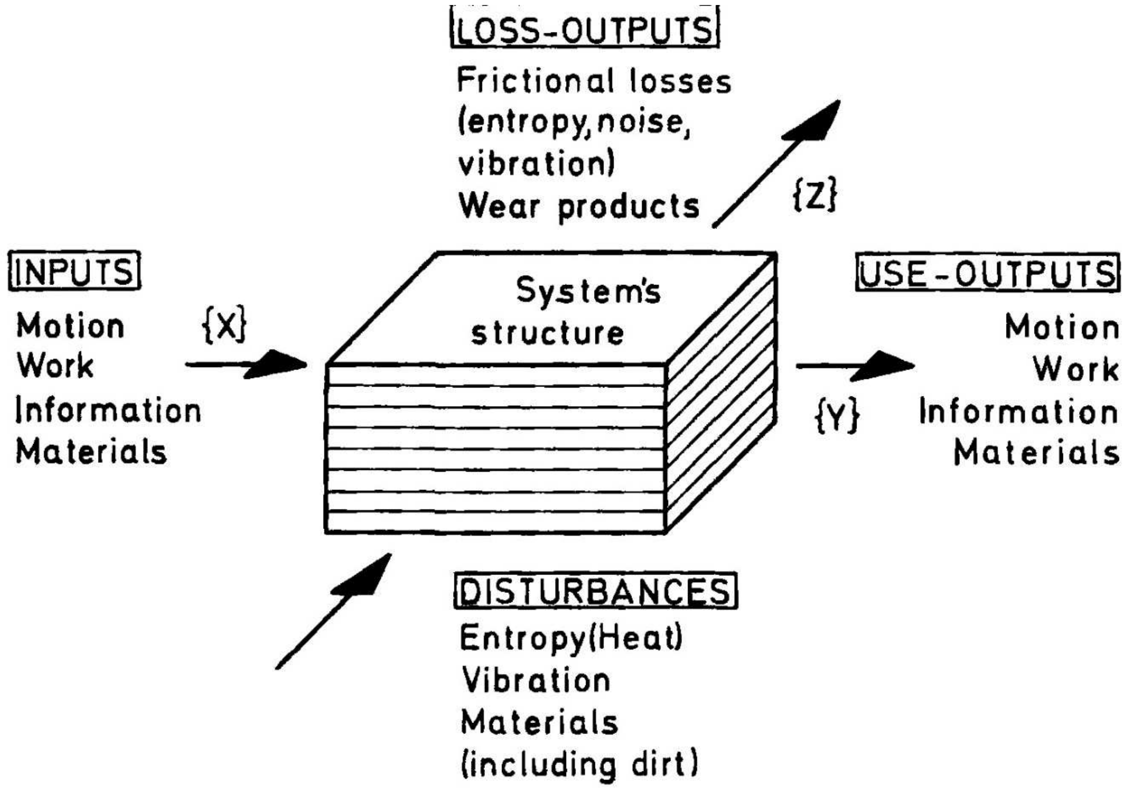

Figure 5: Black-box description of tribo-mechanical systems.

5. STRUCTURE OF TRIBOMECHANICAL SYSTEMS

According to systems theory, the structure of a system is characterized by the elements or components of the system, their relevant properties and their inter relations. The simplest structure of a tribo-mechanical system is given by two solids (1) and (2) exchanging mechanical inputs and outputs through their contact interface.

A few words may be appropriate here on the flow of one or more quantities through a system, implied by the use of the terms "input" and "output", e.g., work or mass. A mass flow is obviously a flow of a material quantity. However, the "flow" of other quantities, such as work, can perhaps be regarded more correctly as an influence of one element upon another. The notion that a quantity "flows" is therefore merely a useful convention, which incidentally helps us to distinguish between the different kinds of process which can occur in a system.

6. TRIBOLOGICAL INTERACTION

The separation and representation of the processes within a mechanical system, onto conceptual planes shown in Figure 6, allows us to concentrate on one aspect of the system at a time.

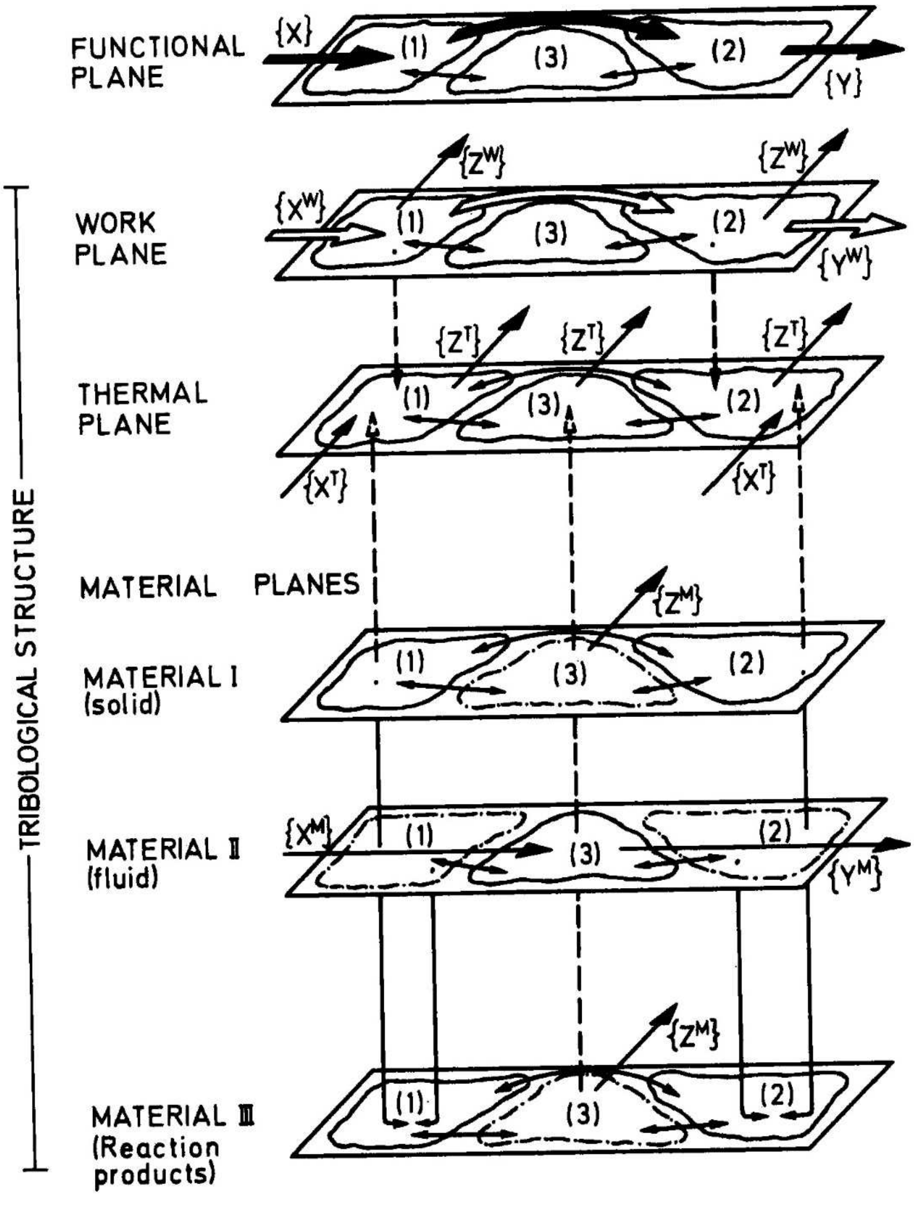

Figure6: The Tribo-process diagram: Conceptual planes of parameters and Processes in a tribo- mechanical system.

1. FUNCTIONAL PLANE

The emphasis on the functional plane, shown in Figure 6, must be on a representation of the technical purpose of the system and the evolution and representation of the parameters which have most immediate relevance to this technical purpose.

2. MECHANICAL PLANE

A system or element may perform mechanical work upon another system or element. Such mechanical work may be measured as the product of a force times a distance (or the product of related variables). Work may also be transferred between elements by the transfer of material in which work is stored. The transfer of work in either manner is referred to as a translation work. Work may also be transmitted from an element or a system as mechanical vibration, or work may be transformed through the tribological interactions in other forms of energy and either stored or emitted or passed to other conceptual planes of the system.

From a generalized energy balance consideration. It follows that the input work must be equal to the use-output work **+** the loss-output energy + the energy stored in the system **+** the energy transformed to other conceptual planes of the system.

3. THERMAL PLANE

The thermal power generation will usually result in the temperature of locations of entropy generation being appreciably higher than their surroundings, resulting in the transfer of the thermal power, by conduction or radiation away from the locations of friction. Heat and entropy can be transferred between systems elements. The transfer of thermal power down a temperature gradient is a unique work process in that the work involved appears as thermal power, i.e., a flow of the same type of quantity as the one being transferred. The net result is that in thermal conduction or radiation, the total thermal-power-flow rate remains constant

I n general, thermal processes are of interest in tribology in so far as the temperature changes involved affect friction and wear processes that is, we are concerned with the relationship between temperature and the mechanical function of the system. This amounts to a concern for the effect of temperature on properties which determine the processes of vibration, friction and wear.

4. MATERIAL PLANE

A principle purpose of a representation on the material planes is to facilitate in sight in to the mass transfer and mass transformation processes which are invariably part of the wear of a mechanical system. In some cases the purpose of the mechanical system may be to transport some material, in which case an evaluation of aspects of the transport of the material will be duplicated on the functional plane and on a material plane. The basic characteristic of wear is the removal of material from one or more machine elements. In some instances, merely a permanent change in shape, through deformation, of a machine element is considered to constitute wear. It may be preferable to call the actual process of the removal of material a process of "attrition", and to apply the term "wear" to cover all the processes in a system which combine to cause attrition. In wear, material may be deformed with in an element. It may also be transferred from one element to another. This process is called translation, which includes not only transfer from one solid element to another, but also attrition, in which case material becomes, as debris, part of the interfacial volume. Furthermore, a material may, through chemical reaction, be transformed to another material.

NOTE: KINDLY REFER BOOK FOR DETAILS OF TRIBOLOGICAL INTERACTIONS
"TRIBOLOGY: A system approach to the science & technology of friction, wear and lubrication.
By *Czichos, H.,*
Unit 3: General Theory of Tribology
Page numbers: 24- 44