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ENERGY-ENTROPY TRIBOANALYSIS OF NATURAL MACHINE - TRIBOSUPERSYSTEM

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Abstract: *Machine is regarded as tribosupersystem which is composed of subsystems – tribosystems. From the position of energy-entropy analysis of adaptive-dissipative nature of states and properties of tribosystem a generalized machine rule is suggested. An idea is discussed about natural and real tribosystems and machines. A number of fundamental principles of tribosynthesis of natural and constructed machines are revealed.*

Keywords: *machine, tribosystem, energy, enthropy, balance, reliability, damageability, wear.*

1. INTRODUCTION

In theory of machines [1] their design starts to be analyzed by presenting machine in the form of structural kinematics scheme (machine skeleton). These kinematics schemes are composed of only two components – links performing relative movements and hinges – tribocouples (Fig.1). The basic problems in clever designed machines are the energy losses in tribocouples. Properly speaking it is this particular problem that makes tribology vital. By singling out a machine (mechanism) from environment by its material outer bounderies we attribute the meaning of system to it. The principle machine subsystem possessing basic functional sense of interconnection elements or movement (energy) transformation objects are friction couples – tribosystems. It is natural that in relation to tribosystems machines constitute tribosupersystems.

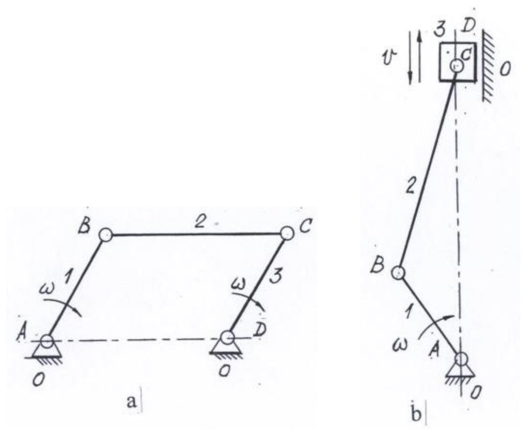

Figure 1. Elementary machines – the simplest lever mechanisms: a) hinge parallelogram; b) crank-type and connecting rod mechanism

2. GENERAL REGULARITIES OF TRIBOSYSTEM EVOLUTION (TRIBOCONTACT)

The study of tribosystem evolution regularities [2] demonstrate that the whole area of tribosystem evolution (Fig.2) can be divided into to characteristic stages – the stage of rinning-in, when preparation of size and structure of friction volume to forming critical equilibrium state takes place and a proper stage of compatible friction, embracing a wide spectrum of possible adapted (optimum) friction structures.

Tribosystem evolution, presented in the form of diagram (Fig.2) has adaptive-dissipative character (1)-(9) and reflects competitive (double) nature of friction.

Evolution curve has a set of principle points (1,2,3,4,5) of transition tribosystem states [2] which strictly obey balanced principle of friction; among these points there exist most characteristic areas of tribosystem behavior reflecting general properties of its non-linear dynamics.

Thus it is possible to see the following conditionly designated points and stages: 0-1 – the area of static friction and deformation strengthening; 1-2 – the area of pumping of excessive energy; 2 the point of seizure and transition of outer friction into the inner one (critical non-stability); 2-3 - the area of forming dissipative structures (formation of heat fluctuation in the friction volume); 3 – the point of minimum compatibility (maximum frictionness); 1-2-3 –the area of compatibility; 4 – the point of wearlessness (anomalous-low friction); 5 – the point of thermal seizure (grip).

An ideal tribosystem evolution is symmetrical. The process starts and finishes in areas of elastic behaviour. Between them there exists a plastic maximum of friction (a strongly-agitated state) as a condition of selforganization and adaptation.

Tribosystem's run in the area of the first stage is unstable and not expedient and associated with a high level of tribosystems damage up to catastrophic one (point 2) – grip and possible score. The area of normal tribosystem operation on the other hand, the area of compatible [3] (adapted [4]) friction which is characterized with the normal level of wear, corresponding to natural and optimum-minimum (as to the wear) reaction of friction volumes to the outer impact (load, enviroment).

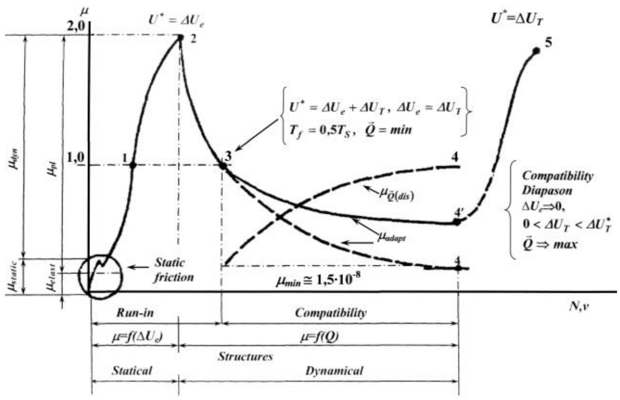

Figure 2. Structural-energy diagram of evolution for rubbing surfaces [2]. In the Figure ΔU_T the change of heat component of internal energy of friction volume being deformed; v the speed of sliding in a friction couple. An asterisk designates critical (limit) friction parameters

3. ABOUT TWO COEFFICIENTS OF FRICTION OF COMPATIBLE FRICTION

The state of any tribosystem in conditions of compatible friction can be evaluated by friction coefficient, which within the frame of energy balance friction equation has the form:

$$\mu = \mu_{adapt} + \mu_{dis_{\vec{Q}}} = \frac{\Delta U_e}{N\ l_f} + \frac{\vec{Q}}{N\ l_f} =$$

$$= \frac{S_U}{S_*} + \frac{\vec{S}_Q}{S_*} = D_{TS} + O_{TS} = 1{,}0, \qquad (1)$$

where $\Delta U_e = V_f^* \Delta u_e = V_{adapt} u_e^*$ - the change of latent energy within deformed friction volume; $\vec{Q} = V_f^* \vec{q} = V_{dis} \vec{q}_*$ - the heat friction effect in the form of dynamic dissipation energy; Δu_e, u_e^* - density change of latent energy and its critical magnitude in the contact volumes; V_f^* - critical volume of compatible (equilibrium) friction; μ_{adapt} ; $\mu_{dis_{\vec{Q}}}$ - adaptive (Leonardo da Vinci) friction coefficient and dynamic component of dissipative friction coefficient; S_U ; $\vec{S}_Q$; S_* - structural (configuration), inertia and critical enthropies of tribosystem; N ; l - normal load and friction way; D_{TS} ; O_{TS} - general parameters of disorder and order of elementary tribosystem (contact volume).

In this equation an integral parameter of state (resistance to movement and damageability) is an adaptive friction coefficient μ_{adapt} of compatible friction. It is connected by enthropies relation $\mu_{adapt} = S_U / S_*$ and so is a probability parameter non operationability state ("annigilation" of outer relative movement owing to accumulation of internal potential energy of different defects and damages of structure), damageability of tribosystem (contact):

$$\mu_{adapt} = \frac{\Delta U_e}{N \ l_f} = \frac{S_U}{S_*} = Desorder. \qquad (2)$$

A dissipative coefficient of compatible friction on the other hand $\mu_{dis_{\vec{Q}}}$ in this case also is an integral parameter of state (assistance to movement, i.e. capacity for work). It is connected by enthropies relation $\mu_{dis_{\vec{Q}}} = \frac{\vec{S}_Q}{S_*}$ and so is a parameter of tribosystem normal operation probability (assistance to relative surfaces movement) or efficiency coefficient of tribosystem:

$$\mu_{dis_{\vec{Q}}} = \frac{\vec{Q}}{N \ l_f} = \frac{\vec{S}_Q}{S_*} = Order. \qquad (3)$$

4. ABOUT DISSIPATIVE COEFFICIENT OF COMPATIBLE FRICTION AS AN EFFICIENCY COEFFICIENT OF TRIBOSYSTEM

Efficiency coefficient of mechanism (machine), possessing *n* tribosystems in succession can be determined by a well known formula for efficiency coefficient of mechanisms connected in sequence [1]:

$$\eta_n = \eta_1 \cdot \eta_2 \cdot \eta_3 ... \eta_n = \frac{A_1}{A_{engine}} \cdot \frac{A_2}{A_1} \cdot \frac{A_3}{A_2} \cdot ... \cdot \frac{A_n}{A_{n-1}} = \frac{A_n}{A_{engine}}.$$

Taking into account that each tribosystem (hinge) possesses a efficiency coefficient of its own by a relation of energy at the exit of tribosystem to energy at its entrance we obtain:

$$\begin{aligned}\eta'_n &= \mu_{dis_1} \cdot \mu_{dis_2} \cdot \mu_{dis_3} ... \mu_{dis_n} = \\ &= \frac{\vec{Q}_{dis_1}}{A_{engine}} \cdot \frac{\vec{Q}_{dis_2}}{\vec{Q}_{dis_1}} \cdot \cdot \frac{\vec{Q}_{dis_3}}{\vec{Q}_{dis_2}} \cdot ... \cdot \frac{\vec{Q}_{dis_n}}{\vec{Q}_{dis_{n-1}}} = \\ &= \frac{\vec{Q}_{dis_n}}{A_{engine}} = \frac{\mu_n^{mach}}{\mu^*}\end{aligned} \qquad , \qquad (4)$$

where $\vec{Q}_{dis_n}$ - system energy at the exit, i.e. work which an operation system is capable to perform (power at the exit); A_{engine} - the work of outer forces (power at the entrance).

Thus, the general mechanic efficiency coefficient η'_n of mechanism (machine), with n tribosystems arranged in sequence is equal to product of dissipative friction coefficients of separate tribosystems (tribosubsystems) μ_{dis_i}, making one general tribosupersystem – mechanism (machine). Here the whole machine may be characterized by some generalized dissipative friction coefficient of a machine - $\mu_{dis}^{mach} = \mu_n^{mach}$ [2].

5. THE RULE OF NATURAL MACHINES AS A TRIBOSUPERSYSTEM

It is known that enthropy of any thermodynamic system equals the enthropies sum of its separate parts (subsystems), i.e. additive magnitude. Since relative critical (configurative) enthropy of tribosystem is equal to unit, then the number of tribosystems in a machine (complex system) determines in essence the machine number n_{mach} - the degree of its complexity or perfection. If we take into account that coefficients of compatible friction of separate tribosystems of machine in balance of each separate tribosystem is always less than a unit, and a machine number is always equal to a whole number then sums of both adaptive friction coefficients $\sum \mu_{adapt_i}$ and dissipative friction coefficients $\sum \mu_{dis_{\vec{Q}} \ i}$ of a machine (tribosupersystem) must be also equal to whole numbers.

Here we can deduce the first conclusion a machine possesses precisely attributes of machine when the sum of adaptive coefficients of compatible friction of its tribosystems comes to be equal to unit:

$$\sum_{1}^{n} \mu_{adapt_i} = 1{,}0\,. \tag{5}$$

As a consequence, a mechanism (machine) is a device where a sum of adaptive coefficients of compatible friction (relative structural (configurative) enthropies of tribosystems) is equal to a unit:

$$\sum_{1}^{n} \mu_{adapt_i} = \sum_{1}^{n} \frac{S_{U_i}}{S_*} = \mu_U^{mach} = 1{,}0\,. \tag{6}$$

It follows that a sum of dissipative coefficients of machine tribosystems or relative rotation-oscilation (inertia) enthropies of dissipative structures [2] is equal to the machine number n_{mach} minus a unit:

$$\sum_{1}^{n} \mu_{dis_{\vec{Q}}\,i} = \sum_{1}^{n} \frac{\vec{S}_{Q_i}}{S_*} = \vec{\mu}_Q^{mach} = n_{mach} - 1 \tag{7}$$

6. INTERPRETATION OF MACHINE RULE IN THE ASPECT OF WEAR

Since dissipative coefficient of compatible friction $\mu_{dis_{\vec{Q}}}$ constitutes ability of dynamic dissipation to facilitate movement then it follows that the sum of dissipative machine friction coefficients $\sum \mu_{dis_{\vec{Q}}\,i}$, equal to a whole number, is an index of capacity for work or some parameter of machine reliability P_Σ:

$$\sum_{1}^{n} \mu_{dis_{\vec{Q}}\,i} = P_\Sigma\,. \tag{8}$$

On the other hand, the sum of adaptive coefficients of compatible friction $\sum \mu_{adapt_i}$ is a characteristic of resistance to movement within the whole machine (accumulated internal potential energy). As it follows from the above analysis, magnitude $\sum \mu_{adapt_i}$ in a machine is always equal to a unit and it determines essence of every machine. Parameter of non-capacity for work (degradation of outer relative movement) in a machine (system) is not equal to zero. The sum of probabilities of tribosystems states (failures) in a machine is equal to a unit:

$$\sum_{1}^{n} \mu_{adapt_i} = O_\Sigma = 1{,}0\,. \tag{9}$$

According to the model of moving critical friction volume [5] this result is to be interpreted in the following way: in a nominal (natural) machine at every particular moment there collapses being in a limiting state one elementary tribosystem – the value of wear is equal to the volume of one equilibrium contact [2]. It is precisely in this way we can enterpret condition (9). Friction coefficient μ_{adapt} equal to a unit [2] characterizes condition of limiting energy state of equilibrium friction contact (of elementary tribosystem).

Here this wear distributed along all tribosystems of a machine constitutes gradual failure which gradually moves tribosystems closer to a limiting wear. This wear concentrated in one tribosystem is to be interpreted as a sudden failure. For example, failure of the first tribosystem – fixed member of kinematic chain. Equality of friction coefficient to a unit for this tribosystem means its critical state. According to a diagram (Fig.2) tribosystem in point 1 got into the area of developing seizure, then score.

Thus, in absolute units the general index of machine functioning can be presented by machine member n_{mach}, which is the sum of indexes of capacity for work (Order) and non-capacity for work (Desorder) of tribosystems of
machine.

$$\sum_{1}^{n} \mu_{dis_{\vec{Q}}\,i} + \sum_{1}^{n} \mu_{adapt_i} = (n_{mach} - 1) + 1 = .$$

$$= Order + Desorder = n_{mach}\,. \tag{10}$$

In relative units the machine serviceability indexes may be presented in a familiar state reflecting principles of states relativity – Order and Disorder of tribosystems constituting machine

$$\frac{\sum_{1}^{n} \mu_{dis_{\vec{Q}}\,i}}{n_{mach}} + \frac{\sum_{1}^{n} \mu_{adapt_i}}{n_{mach}} = \left(\frac{n_{mach} - 1}{n_{mach}}\right) + \frac{1}{n_{mach}} = 1 \tag{11}$$

or principles of operation probability (reliability) and probability of failure (damageability) of system

$$P(t) + O(t) = 1. \quad (12)$$

Where

$$\frac{\sum_1^n \mu_{dis_{\vec{Q}}\, i}}{n_{mach}} = P(t), \quad (13)$$

and

$$\frac{\sum_1^n \mu_{adapt_i}}{n_{mach}} = O(t). \quad (14)$$

It follows from these relations that probability of failure free operation of ideal machine grows with growing member of tribosystems (the degree of complexity or perfection), since absolute (instant) failure magnitude always equals collapse (limiting state) of one elementary tribosystem and, consequently, probability of failure diminishes.

7.TRIBOSUPERSYSTEM FRICTION COEFFICIENTS

In a most general case it is possible to write down the following relations for machine (complex system):

$$\mu^{mach} = \sum_1^n \frac{S_i}{S_*} = \frac{S_1}{S_*} + \frac{S_2}{S_*} + \frac{S_3}{S_*} + \ldots$$

$$\cdots + \frac{S_n}{S_*} = n_{mach};$$

$$\mu_U^{mach} = \sum_1^n \frac{S_{U_i}}{S_*} = \frac{S_{U1}}{S_*} + \frac{S_{U2}}{S_*} + \frac{S_{U3}}{S_*} + \ldots$$

$$\cdots + \frac{S_{U_n}}{S_*} = 1{,}0$$

$$\vec{\mu}_Q^{mach} = \sum_1^n \frac{\vec{S}_{Q_i}}{S_*} = \frac{\vec{S}_{Q1}}{S_*} + \frac{\vec{S}_{Q2}}{S_*} + \frac{\vec{S}_{Q3}}{S_*} + \ldots$$

$$\ldots + \frac{\vec{S}_{Q_n}}{S_*} = n_{mach} - 1{,}0;$$

$$\mu^{mach} = \mu_U^{mach} + \vec{\mu}_Q^{mach} = n_{mach}. \quad (15)$$

Here S_i, S_n - enthropies of i' and n' machine and hinges numbers involved in it. In this connection tribosystems.

It is expedient to attribute to these relations the meaning of the most characteristic equations of machine. Here parameters μ^{mach}, μ_U^{mach}, $\vec{\mu}_Q^{mach}$ - may be regarded as some generalized coefficients of machine friction.

8. TRIBOLOGICAL STRUCTURAL LEVELS OF NATURAL MACHINES

Information mentioned above about generalized properties of machines (tribosupersystems) allows to single out and regard some equally characteristic indexes of ideal (nominal) machines, i.e. machines, possessing optimum – natural properties. It follows from the rule $\sum \mu_{adapt_i} = 1{,}0$ that not all digital values of adaptive coefficients of compatible (optimum) friction μ_{adapt_i} may in sum give unit, but only quite definite ones (Table 1).

Table 1. Possible set of natural tribosystems forming a machine (tribosupersystem)

μ_{adapt_i}	$\mu_{dis_{\vec{Q}}\, i}$	$n_{mach_i} = \frac{1}{\mu_{adapt_i}}$
0,5	0,5	2
0,25	0,75	4
0,2	0,8	5
0,1	0,9	10
0,05	0,95	20
0,04	0,96	25
0,025	0,975	40
0,02	0,980	50
0,01	0,990	100
0,005	0,995	200
0,004	0,996	250
0,0025	0.9975	400
0,002…	0,998…	500…

And so on.

As it follows from Table 1, there exist a set of nominal (natural) tribosystems and correspondingly a set of natural machines (tribosupersystems). The whole diversity of tribosystems made by man should be regarded as real (constructed) tribosystems and machines.

9. THE RULE OF MACHINES TRIBOSYNTHESIS

In the theory of mechanisms and machines in the part concerning their making from the simplest constituents – links and elements, L. Assur rule [1] is well known Table 2, according to which the simplest level mechanisms obey the rule: relationship between the number of links n and link elements (hinges) p_5 in an attached to the leading link (the first class mechanism (Fig.3)) is equal to: $p_5 = 3/2 \cdot n$.

So any synthesized mechanism possesses discrete levels of links creating the rule of tribo-optimal machine $\sum \mu_{adapt_i} = 1{,}0$ with the rule of quantitative structural machine design has a considerable scientific and practical interest.

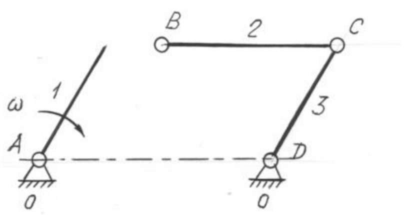

Figure 3. Scheme of kinematic chain of hinge parallelogram where link 1 and fixed member A – is the first class mechanism and the joined Assur group of the second class in the form of links 2 and 3 and hinges B, C, D

Table 2. Choice of friction coefficients in tribosystems for mechanisms (machines).

№	n	p_5	n_{mach}	$\sum_{1}^{n} \mu_{adapt\ i} = 1{,}0$
1	2	3	4	0,25×4=**1,0**
2	4	6	7	0,05+0,25+(0,2×2)+(0,1×3) =**1,0**
3	6	9	10	0,1×10=**1,0**
4	8	12	13	(0,05×8)+0,2+(0,1×4)=**1,0**
5	10	15	16	0,05×12)+(0,1×4)=**1,0**
6 …	12 …	18 …	19 …	0,1+(0,05×18)=**1,0…**

Table 2 presents digital values of friction coefficients for friction couples of mechanisms, designed according to L. Assur rule. As it is seen, the calculated values of friction coefficients (Table 1) of optimal machines allow to forms tribo-optimal (nominal) machines. The rule of unit mentioned above accomplishes for any combination of links and hinges number within L. Assur model for flat mechanisms.

Possessing from digital regularities shown above, it is possible to construct and consider structural levels of natural (optimal) machines tabulated in Table 3.

10. ABOUT CAPACITY FOR WORK OF COMPLEX SYSTEM – TRIBOSUPERSYSTEMS

In real practice [6,7] capacity for work of complex systems is evaluated by probability of failure free operation as a product of subsystems probabilities:

$$P(t)' = P_1(t) \cdot P_2(t) \cdot P_3(t) \ldots P_n(t). \qquad (16)$$

And it is believed that reliability of complex systems even with the same reliability of each subsystem $P(t)' = P_i^n(t)$ drops abruptly. But this conclusion is not one – valued and needs analysis from physics and essential positions.

Really, if we just increase number of subsystems with equal probability of failure free operations of subsystems, then opinion [6,7] is supported. But if we increase the number of subsystems according to structural-hierarchical model (Table 3) with the corresponding lead of probability of dissipative friction coefficient and diminishing probability of non-capacity for work (adaptive friction coefficient) of each subsystem (Table 3) when we have the growth of probability for the whole system failure free operation (machine efficiency coefficient).

Let us take for example crank-rod mechanism with 4 hinges. According to Table 3 an adaptive coefficient of friction equals 0,25 and dissipative one – 0,75. Efficiency coefficient of such elementary machine equals $0{,}75^4 = 0{,}316$. Now it takes these friction coefficients, correspondingly 0,025 and 0,975. Here we get over to a new leading structural friction level. In this case efficiency coefficient of such tribosynthesized (constructed) machine will equal $0{,}975^4 = 0{,}9367$.

The calculation results presented in Table 3 convincingly demonstrates that probability value of failure free operation (reliability) of subsystems joined by common operation starts to increase with the increase of tribosystems (subsystems) member and sufficiently quickly reach some stable level equal to 0,367. On the other hand, probability of system capacity for work $P(t)$ constantly grows (wear aspect). The level of constancy $P'(t)$ of complex systems as it follows from the value of reversed $P'(t)$ possesses specific and deep physics meaning, since $\frac{1}{P'(t)}$ constitutes global constant – limiting number $\mathbf{e}$.Since parameter $P'(t)$ is nothing but product of dissipative friction coefficients of machine tribosystems or machine efficiency coefficient [2], then we should speak about constant character of efficiency coefficient of all natural machines. Really, all natural machines possess the same efficiency coefficient.

As it has been said above, if we form a system from subsystems of Table 1, then increase of subsystems number does not lead to diminishing reliability parameter, but on the contrary it takes place an increase of this parameter and its tendency to some constant value $\mathbf{e}$. Analysis of quantitative attributes of natural machines (Table 3) demonstrates [2] that equation of such natural or nominal machine may be an equation determining the principle of structuring limitation.

$$P'(t) = \frac{1}{\mathbf{e}} = \mathbf{e}^{-1} \tag{17}$$

or

$$P'(t) = \frac{1}{\left(1+\frac{1}{n}\right)^{n}} = \left(1+\frac{1}{n}\right)^{-n}. \tag{18}$$

Substituting machine number n_{mach} for number n tending to infinite (non-limiting) increase, which characterize the number of its tribosystems (subsystems) we get an equation of ideal or nominal machine

$$P_{mach}(t) = \frac{1}{\left(1+\frac{1}{n_{mach}}\right)^{n_{mach}}} =$$

$$= \left(1+\frac{1}{n_{mach}}\right)^{-n_{mach}} = \frac{1}{\mathbf{e}} = const\ . \tag{19}$$

Since value $P_{mach}(t)$ is nothing but value of machine efficiency or the efficiency coefficient η_{mach} (Table 3) [2], then equation of the machine gets naturally objective or physics meaning:

$$P_{mach}(t) = \eta_{mach} = \frac{1}{\left(1+\frac{1}{n_{mach}}\right)^{n_{mach}}} =$$

$$= \left(1+\frac{1}{n_{mach}}\right)^{-n_{mach}} = \frac{1}{\mathbf{e}} = const\ . \tag{20}$$

Thus, when making complex systems from units composing this system, we should speak not about diminishing reliability of machine operation at increasing subsystems number, but about tending this value which is nothing but system efficiency to some characteristic number $\mathbf{e}$, which is in its turn a characteristics of system – of nominal machine or tribosupersystem as such. It follows from Table 3 that all nominal, i.e. natural machines possess equal efficiency and an increase of complexity degree (perfection) of natural systems is determined by their tendency to a state with universal constant.

11. SYNOVIA FRICTION COEFFICIENT OF NATURAL MACHINES

To check the calculated set of natural machines (Table 2,3) it is necessary to study real living machines, e.g. structural, kinematic schemes of man and horse. These structural kinematic schemes are skeletons of man and horse. The basis of these skeletons for kinematic couples: links – bones and tribopairs – joint hinges.

According to encyclopaedia information [8,9] human skeleton is composed of 270 bones in the early age and of 220 bones in mature age. The horse skeleton is composed of 252 bones. As it is seen this number of links (n_{mach}) in these living machines correspond to a calculated set of natural machines with the machine number $n_{mach} = 250$. This result allows to assess the value of friction coefficient of synovial liquid of joint hinges of living organisms (machines).

From Table 3 we have for $n_{mach} = 250$ the value of adaptive friction coefficient equal to $\mu_{adapt} = 0{,}004$. This value should be taken for synovia friction coefficient. Modern tribology treats this level of friction coefficient as the level of superlubrication.

Naturally if we consider that friction in living machines has the most optimal, i.e. perfect level then quantitative level of the most perfect lubrication determined by modern tribology should be acknowledged as objective one.

Table 3. Natural machines structural levels

$\mu_{ad_i} = S_U$	$\mu_{dis_i} = \vec{S}_Q$	n_{mach}	$S_Q^{n_{mach}} = P(t)'$	$\dfrac{1}{P(t)'}$	$P(t) = \dfrac{n_{mach} - 1}{n_{mach}}$
0,5	0,5	2	$0{,}5^2$=0,25	4	0,5
0,25	0,75	4	$0{,}75^4$=0,316406	3,16049	0,75
0,2	0,8	5	$0{,}8^5$=0,32768	3,05175	0,8
0,1	0,9	10	$0{,}9^{10}$=0,348678	2,86797	0,9
0,05	0,95	20	$0{,}95^{20}$=0,358486	2,789509	0,95
0,04	0,96	25	$0{,}96^{25}$ =0,360396	2,774725	0,96
0,025	0,975	40	$0{,}975^{40}$=0,363232	2,753061	0,975
0,02	0,980	50	$0{,}980^{50}$=0,364169	2,745977	0,980
0,01	0,990	100	$0{,}990^{100}$=0,366032	2,732001	0,990
0,005	0,995	200	$0{,}995^{200}$=0,366957	2,7251088	0,995
0,004	0,996	250	$0{,}996^{250}$=0,367142	2,7237417	0,996
0,0025	0,9975	400	$0{,}9975^{400}$=0,367419	2,7216874	0,9975
0,002	0,998	500	$0{,}998^{500}$=0,367511	2,7210051	0,998
0,001	0,999	1000	$0{,}999^{1000}$=0,367695	2,719645	0,999
…					
0,0001	0,9999	10000	$0{,}9999^{10000}$=0,367861	2,718418	0,9999
…					
0,00001	0,99999	100000	$0{,}99999^{100000}$=0,367877	2,718295	0,99999

And so on.

12. THE RULE OF REAL MACHINES FORCING

As we see above (Table 3) the whole set of natural machines tends to some state where many living systems (machines) have a constant efficiency coefficient.

Real machines designed by man are made forced for larger operation, i.e. for larger efficiency coefficient.

The first way of making forced (heavily loaded) machine – is its tribological synthesis by transiting friction to a lower hierarchy level – diminishing adaptive friction coefficient (from $\mu_{adapt} = 0{,}25$ to $\mu_{adapt} = 0{,}025$), e.g. four-link crank-rod mechanism (one cylinder ICE). Here we may enlarge efficiency coefficient a great deal (see above - $\mu_{diss}^4 = 0{,}975^4 = 0{,}9367$)). Here the machine rule is violated, i.e. we have $\sum \mu_{adapt\,i} < 1{,}0$, but by means of forcing loading N and speed v (see diagram, Fig. 1) the machine rule $\sum \mu_{adapt\,i} = 1{,}0$ is restored, and relative wear resistance increases.

The second way – is joining together the simplest mechanisms with the increased efficiency coefficient – transition from one cylinder ICE to multi-cylinder ones, e.g. to 10-

cylinder ICE ($n_{mach} = 40$). Here efficiency coefficient diminishes to practically former level corresponding to 40-links mechanism $(\mu_{diss}^{4})^{10} = (0{,}975^{4})^{10} = 0{,}363$. At the same time we see an increase of aggregated machine horse-power and relative wear resistance.

Further follows a new transition to a lower adaptive friction coefficient (Table 3), i.e. $\mu_{adapt} = 0{,}004$ correspondingly increases loading level N or speed v, increases relative wear resistance, efficiency coefficient:

$$\mu_{diss}^{40} = 0{,}996^{40} = 0{,}8518.$$

If $\mu_{adapt} = 0{,}002 \div 0{,}001$, machine efficiency coefficient equals $\mu_{diss}^{40} = (0{,}998 \div 0{,}999)^{40} = 0{,}923 \div 0{,}96$, etc.

13. CONCLUSION

The number of machines (degree of complexity) is determined by the number of kinematic pairs (tribosystems) of its kinematic chain.

The rule of machine (optimal) is determined by the sum of adaptive and dissipative friction coefficients of compatible tribosystems.

In a system-compatible, natural machine the sum of the adaptive friction coefficients of the kinematic chain joints must be equal to unit.

The rule $\sum_{1}^{n} \mu_{adapt_i} = 1{,}0$ shows that in any machine the operation of its tribosystems will strive for implement this rule. Exceeding this rule leads to increased damage to the machine.

All natural machines (living systems) have the same efficiency of 0.367.

To improve the performance of the machine and at the same time its reliability (probability of failure) should decrease the values of the coefficients of the adaptive friction of tribopairs taking into account the structural levels (tab.3) compatible friction parameters. It is to this that the essence of the tribological factor of reliability of machines is reduced.

Real, forced machines have a rule of the machine in the form of - $\sum_{1}^{n} \mu_{adapt_i} << 1{,}0$. This ensures the lowest wear of the machine tribosystems with an increased efficiency.

The coefficient of friction of synovia is about 0.004 and below. This coefficient of friction characterizes the super lubrication of the hinges of living systems (natural machines).

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