SCIENTIFIC PROBLEMS
OF MACHINES OPERATION
AND MAINTENANCE
4 (160) 2009

M. KANDEVA*, M. MANOLOVA-DANEVA**

The functional atom of tribology and its application

Key words

Functional atom, macrostructure of body, friction, wear, lubrication.

Summary

The notion „functional atom" (FA) was created in the Center of Tribology at the Technical University of Sofia, in the field of tribology as interdisciplinary science. The functional atom is formed of 3 components similarly to the basic contact system „body-contact-counterbody". This notion assigns the central role of contacts in the interaction of bodies in nature, techniques and society.

The idea for the FA is expressed in the fact that its two alternatives "body" and „counterbody" do not interact directly, but through the third body – the contact between them, and the contact networks in the whole functional space of the atom.

Six postulates as basis of the model, theory and application of FA are formulated in the present work. The application of FA is illustrated with concrete examples: the development of the macrostructure of tribology as interdisciplinary science;formulation and using of General law of the contact interaction of bodies in the functional space of tribology – friction, wear, lubrication, contact deformation, contact conductance and capillarity. Other illustrations and applications of the model of FA in triboecology, tribotechnologies, engineering education, etc.

1. Introduction

Tribology is a strongly active interdisciplinary science developed in the second half of the 20th century. Its growth rate is determined by the rate of formation of the inside, outside and its own contacts in its functional space.

* Tribology Center – Sofia, Bulgaria.
** Interdisciplinary Civic Academy – Sofia, Bulgaria.

The external mark of this development is the appearance of new notions, sections, trends, and disciplines.

Some of the new notions are the notions *functional atom, functional space, contact webs,* and *contact zero* as privilege point of view in contact systems, etc.

Some of the new trends are *contact capillarity, contact porosity, contact displacement, contact deformation,* etc., and between the new achievements are the *principles, laws, and postulates* of tribology. The new tribological disciplines related to the forming of outside contacts and contact interactions with other scientific disciplines are *tribomechanics, tribotechnologies, nanotribology, tribochemistry, biotribology, triboecology,* etc. These disciplines are on the frontier and interdisciplinary in their nature, and are a sign of the between-science contacts between mechanics, technologies, chemistry, biology, ecology, etc.

The present work justifies several ideas of tribology in their general context, i. e. some of the notions are seen in their universal flavour for the whole scientific functional space. Attention is drawn to the notion **functional atom of tribology** (FAT) as notion with fundamental general-scientific essence, as well as to some illustrations of its applications.

2. Exposé

The idea of the functional atom (FA) was created in 1970 in Moscow, where N. Manolov developed and a defended dissertation on the ultrasound conductance of two contacting bodies. The measurement showed that the conductance of these two bodies depended significantly, not only on the nature of the two bodies, but more on the manner of the way they were coming in contact (the state of the contact between them). Hence, the total conductance of the two bodies is superimposed by the conductance of the bodies and the conductance of the contact between them. This lead to the idea that, for the description of the real behaviour of the contact system of two bodies, the system has to be considered as built by three bodies: two physical ones and a third one – the functional body between them [1, 2].

Since that year, the contact as third functional body became a central scientific subject of the Laboratory of tribology at the Technical University - Sofia [3–6].

2.1. Essence and models of the functional atom

Philosophy and philosophers relate the unity of world with the common ontological beginning for all things that are being. According to Spinoza, this is the substance, according to Marx – the matter, according to Hegel – the idea, and according to Descartes the beginnings are two: material and spiritual divided by demarcation line (dualism).

The notion functional atom (FA) is based on another ontological model, analogically to monism and dualism called **trialism**. According to trialism, each thing that is being is tri-unique. Trialism does not deny the material and spiritual essence of the being, but complements them by a third contact beginning between them according to the formula "material-cultural-spiritual." The non-stable character of dualism should be overcome using culture as third beginning. Trialism is the first pluralistic stable model of world development. The sustainability of the idea of God as tri-unique essence – God-Father, God-Son, and God-Spirit is good illustration for that.

The natural science relates the idea of the unity of world with the notion of the **atom** considered as basic constructive unity of its material essence. The notion of the atom has a long history and is connected with the names of Democtrit, Leucippus, Dalton, Marie and Pierre Curie, Rutherford, Schrödinger, Bohr, etc. The quantum model of the atom corresponds to the dualistic idea about the unity of particle and wave [7].

The functional atom FA as idea unifies the tri-unique ontological (philosophical) model of the world with the three-component model of the elemental contact tribosystem.

As a structure, each functional atom A consists of 3 elements: two alternatives A_1 and A_2, and third functional element A_3 as contact between the alternatives. The basic functions of the contact elements are the dividing, unifying, and realising of the alternatives of each wholeness of being in its unity.

The notion FA is interdisciplinary and is a product of tribology according to its basic formula "body-contact-counterbody." Opposite to the orthodox idea of the atom, the functional atom is basic constructive unity of each thing being in nature, society, and techniques. Fig. 1 shows three geometrical ways for illustrating the model of FA: tetrahedral, spherical, and planar.

Why everything being should be tri-unique? Because it necessitates functional (living) space. Functional space cannot be formed by one or two

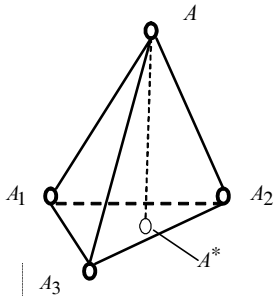

Fig. 1 a): Tetrahedral model of FA

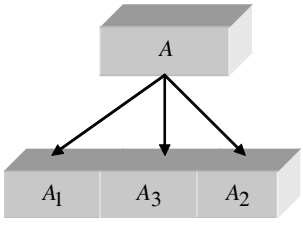

Fig. 1 b): Planar model of FA

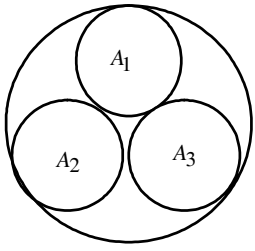

Fig. 1 c): Spherical model of FA

elements. In fact, all that is being, has to be somewhere, some time, and somehow, i. e. the physical presence of thing A is presented by its spatial location A_1, its spiritual presence - by the time A_2, and its functional presence – by the contact formation between space and time A_3. The functional space of the thing A is defined by the volume restricted by the four points A, A_1, A_2, A_3.

2.2. The functional atom as a kernel of new interdisciplinary approach

The interdisciplinary approach is a system approach of three-component formations at different levels and cross-sections, directed to overcome some problem situation.

Opposite to deductive and inductive approaches, going respectively from the general to the special and vice versa for the concrete problem situation, the interdisciplinary approach affects directly the problem situation by the model and postulates of FA.

As a part of the being of the interdisciplinary approach, the postulates of FA form the universal functional atom (Fig. 2).

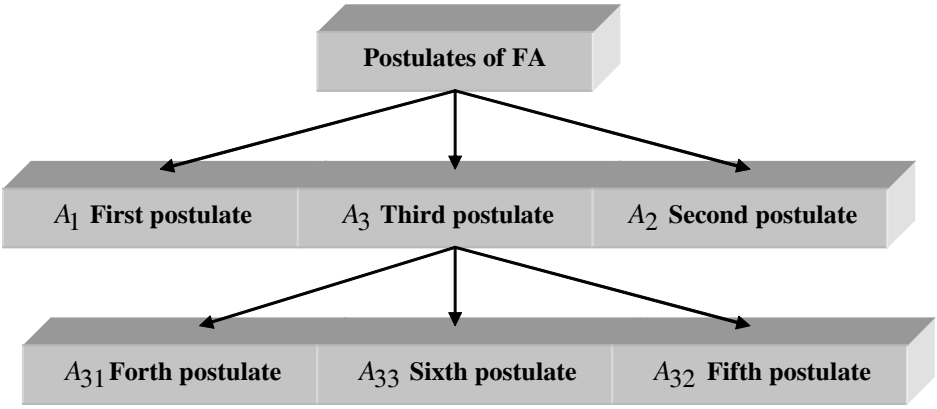

Fig. 2: Functional atom of the postulates of FA on two levels

A_1 – **First postulate:** Each thing, which is being in this world, forms a functional atom.

A_2 – **Second postulate:** Each atom A being in this world, consists of finite or infinite number of atoms located on different levels and cross-sections in its functional space.

A_3 – **Third postulate:** Each atom A despite of its nature (material, spiritual, cultural), from its level or cross-section of being, is a tri-unique formation consisting of two alternatives A_1, A_2 and contact A_3 between them.

Its current state is assessed by the gravity centre of the plane of triangle A_1, A_2, A_3, where the atom A is being.

A_{31} – **Forth postulate:** Each atom A on the arbitrary level and cross-section is stable, if its orthogonal projection A^* (Fig. 1) is inside the triangle A_1, A_2, A_3.

A_{32} – **Fifth postulate:** Each atom A is open towards other atoms A_i, if its communication potentials η_i with the other atoms are different of zero.

A_{33} – **Sixth postulate:** The functionality and effectiveness of the interaction of the atom A with system of other atoms A_i is optimal, if its components AA_1, AA_2, AA_3 are orthogonal and equal, and its communication potentials η_i have unity value.

2.3. Some applications of the functional atom

General law of contact interaction of functional atoms of being

Two arbitrary atoms α and β are considered, which interact through the atom γ in its cognitive cross-section. The alternatives of the atom γ are $A_1 = \dfrac{dA}{dR}$ and $A_2 = \dfrac{R}{A}$, and $A_3 = K$ is the contact between them (Fig. 3).

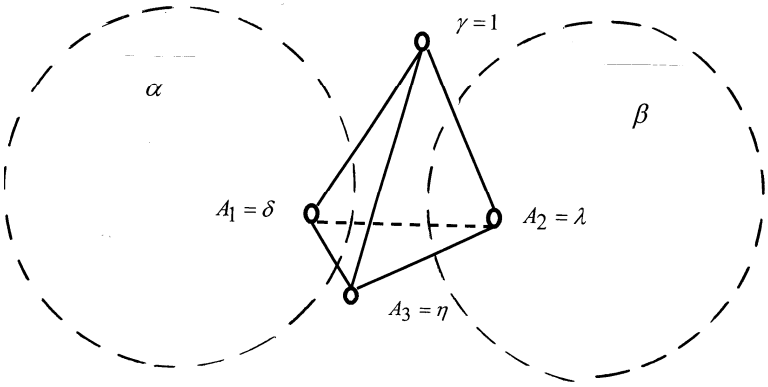

Fig. 3. Functional atom of the General law of the contact interaction

Functional cognitive space is measured by the volume V of the atom γ, i.e.

$$V = \alpha_o K \frac{dA}{dR} \frac{R}{A} \tag{1}$$

Here, A is the action of the atom α on the atom β designated as external action A, and R is the reaction of β caused by the action of α; $\alpha_o = const$, different for the different tetrahedrons.

Let have the designations: $\frac{R}{A} = \lambda$ - reactive potential; $\frac{dA}{dR} = \delta$ - active potential; $\frac{\alpha_o K}{V} = \eta$ - communication potential.

With the above designations the volume V from (1) obtains the form:

$$\eta.\delta.\lambda = 1 \tag{2}$$

Formula (2) has an universal cast as General law for the contact interaction, according to which the product of the three potentials – active δ, reactive λ and communication η is always unity despite of the nature and the state of the atoms, which interact.

In differential form the law (2) is as follows:

$$\frac{dR}{R} = \eta \frac{dA}{A} \tag{3}$$

i.e. the relation between the relative change of the action and the reaction is realised through the communication potential η.

For tribology, the most important of the three potentials in the General law of contact interaction is the communication potential, as it is directly related with the role of the contact in tribosystems.

The General law of the contact interaction, applied to mechanical interaction $A(t) = R(t)$, i. e. the action is equal to the reaction, leads to the result:

$$\delta = \lambda = 1 \tag{4}$$

And from (2), we obtain that communication, in this case, is also characterised by communication potential unity, i.e.

$$\eta = 1 \tag{5}$$

Hence, the mechanical paradigm, which dominates the classical science, is characterised by equal potentials and according to the General Law of the contact interaction this paradigm treats an idealised case.

When the action A is multi-component, i. e. $A = A_1 + A_2 + ... + A_n = \sum_{i=1}^{n} A_i$, (3) obtains the form:

$$\frac{dR}{R} = \eta_1 \frac{dA_1}{A_1} + \eta_2 \frac{dA_2}{A_2} + ... + \eta_n \frac{dA_n}{A_n} = \sum_{i=1}^{n} \eta_i \frac{dA_i}{A_i} \tag{6}$$

where,

$$\eta_i = \frac{\eta}{\frac{A_1}{A_i} + \frac{A_2}{A_i} + ... + 1 + ... + \frac{A_n}{A_i}}; \frac{dA_i}{A_i} \neq 0; \frac{dA_{i+1}}{A_{i+1}} = 0; \; i = 1,2,...,n \tag{7}$$

Determination of the communication potentials in the contact interaction at rolling

According to the General tribological law (6), the law of rolling friction in differential form is

$$\frac{dT}{T} = \eta_1 \frac{dN}{N} + \eta_2 \frac{dR}{R} \tag{8}$$

where, N and R are the normal load and the radius of the rolling body, and η_1 and η_2 are communication potentials between friction and factors N and R (Fig. 4)

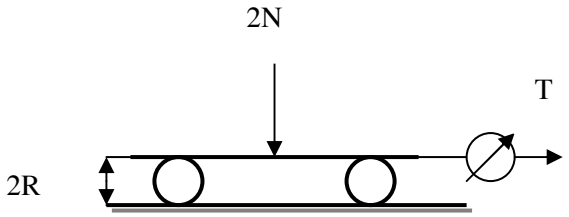

Fig. 4. Scheme of the device for the study of rolling friction

As known in tribomechanics, the law of rolling friction is given in the form:

$$T = f \frac{N}{R} \tag{9}$$

where, f is coefficient of rolling friction.

Then we take logarithm and differentiate (9)

$$\ell nT = \ell nf + \ell nN - \ell nR; \; \frac{dT}{T} = \frac{df}{f} + \frac{dN}{N} - \frac{dR}{R}; \; f = const$$

i. e. $$\frac{dT}{T} = \frac{dN}{N} - \frac{dR}{R} \tag{10}$$

Having in view (10) and (8), tribomechanics states that

$$\eta_1 = 1,\ \eta_2 = -1 \tag{11}$$

which is in accordance with the pure mechanical character of formula (5).

Whether the tribological law for the contact interaction at rolling (8) is different from the tribomechanical law (10) is to be found through experimental determination and the study of the communication potentials η_1 and η_2.

For that purpose formula (10) is reduced to

$$\frac{dT}{T} = \eta_1 \frac{dN}{N} \text{ under the condition that } R = const \tag{12}$$

The experimental relationship $T = \psi(N)$ at $R = const$ (Fig. 5)

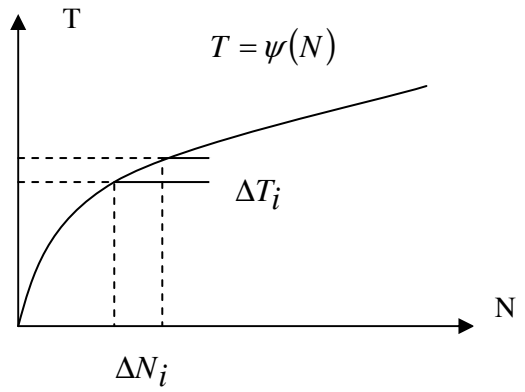

Fig. 5. Experimental relationship $T = \psi(N)$

The communication factor η_1 is defined experimentally from the plot in Fig. 5 for different values of the normal load $N_1, N_2, ...N_i$. By small increments ΔN_i around N_i, the increase of the friction force and ΔT_i are in Fig. 5.

Using formula (12) for η_1 in point N_i, we obtain

$$\eta_1(N_i) = \frac{\Delta T_i . N_i}{T_i . \Delta N_i};\ i = 1,2,...6 \tag{13}$$

Depending from the results obtained for η_1 the function $\eta_1 = \eta_1(N)$ can be linear or nonlinear. The linear case corresponds to the tribomechanical law, and the nonlinear one – to the tribological law. Similarly, the communication potential $\eta_2 = \eta_2(R)$ for $N = const$ is also studied.

The law of rolling friction can be sometimes tribomechanical, and in other cases – tribological. This requires the study of the communication potentials η_1 and η_2 as criteria for the character of the particular contact system.

The relation between the communication potential η_1 and the coefficient of friction f is given by the formula:

$$\eta_1 = \frac{\Delta T.N}{T.\Delta N} = \frac{\Delta T.N.R}{f.N.\Delta N}, \text{ i. e. } f = \frac{\Delta T.R}{\Delta N.\eta_1(N)} \tag{14}$$

Law for the loss of fluids through contact gaps

The multiple contact joints in water and gas, and in the lines of the chemical industry cause leakage of gases and liquids, which leads to mass and energy loss. The most dangerous for the environment are toxic materials, coming from the chemical installations into the environment. The control of these processes requires their study in the form of a law for the loss of fluids L in $[\ell / h]$ (litres per hour) through contact gaps.

It is not difficult to see that the flow rate L of the losses is in the general case dependent on fluid pressure p at the input of the contact joint, on the force N pressing the contact, on the hardness HB of the contact surfaces, on their roughness R_z, the contact gap h etc., i. e. $L = L(p, N, h, R_z, HB...)$.

The principle scheme of the experimental study is shown in Fig. 6.

Opposite to tribomechanical laws related to friction, wear, and lubrication, the law we want to find belongs to the group of complex laws of tribology, as the factors, which influence the losses, are multiple (three and more). The procedure based on the General law of the contact interaction is applicable for the searching of this type of laws too. In fact, on the first level, we can write the general law in the form:

$$\frac{dL}{L} = \eta_1 \frac{dp}{p} + \eta_2 \frac{dh}{h} \tag{15}$$

where η_1 and η_2 are communication potentials of the mass flow rate losses corresponding to the pressure p and the contact gap h.

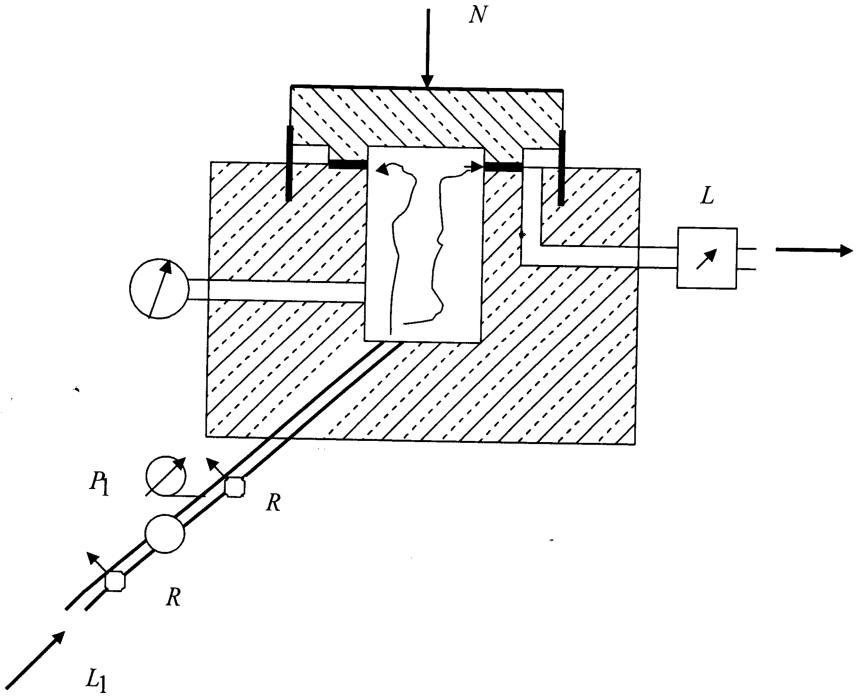

Fig. 6. Scheme for experimental study the mass flow rate of losses through the contact joint

On the other hand, for the contact gap according to the same law is valid

$$\frac{dh}{h} = \eta_3 \frac{dN}{N} + \eta_4 \frac{dR_z}{R_z} + \eta_5 \frac{dHB}{HB} \tag{16}$$

where η_3, η_4, η_5 are communication potentials corresponding to the relative load, the relative roughness and relative hardness of the rough surfaces.

From (15) and (16) follow

$$\frac{dL}{L} = \eta_1 \frac{dp}{p} + \eta_2\eta_3 \frac{dN}{N} + \eta_2\eta_4 \frac{dR_z}{R_z} + \eta_2\eta_5 \frac{dHB}{HB}$$

or

$$\frac{dL}{L} = \eta_1 \frac{dp}{p} + \eta_{23} \frac{dN}{N} + \eta_{24} \frac{dR_z}{R_z} + \eta_{25} \frac{dHB}{HB} \tag{17}$$

At $R_z = const$ and $HB = const$ the problem for the loss is reduces to

$$\frac{dL}{L} = \eta_1 \frac{dp}{p} + \eta_{23} \frac{dN}{N} \quad \text{or} \quad \int_{L_o}^{L} \frac{dL}{L} = \eta_1 \int_{p_o}^{p} \frac{dp}{p} + \eta_{23} \int_{N_o}^{N} \frac{dN}{N} \tag{18}$$

Taking the antilogarithm for $\eta_1 = const$ and $\eta_{23} = const$, the law $L = L(p, N)$ obtains the form:

$$L = L_o \left(\frac{p}{p_o} \right)^{\eta_1} \left(\frac{N}{N_o} \right)^{\eta_{23}} ; p \geq p_o ; N \geq N_o ; p_o > p^* ; \eta_1 > 0 ; \eta_{23} < 0 \quad (19)$$

where p^* is the pressure required to overcome the impenetrability of the contact.

Conclusion

- The General Law of the contact interaction in the field of tribology is reduced to the laws of tribomechanics, when the contact potentials are constant values and in particular are equal to unity.
- The laws in tribology are complex, if the communication potentials are three or more.
- The General law of the contact interaction is applicable for all contact systems, regardless of their essence – natural, technical or social. For example, the law is applicable for the population of the human society, regarded as contact system of human individuals.

References

[1] Manolov N., Акустический метод исследования контакта твердых тел, автореферат, Москва, 1970 (Acoustic method for study of bodies contact, Dr. Dissert., Moscow, 1970).
[2] Czichos H., A Systems Approach to the Science, 1978, Moscow
[3] Garkunov D.N., Научные открытия в триботехнике, Эффект безызносности при трении. Водородное изнашивание металлов, Москва, 2004 (Scientific inventions in tribotechnics. The effect of no-wear by friction. Hydrogen wear of metals., Moscow, 2004)
[4] Kandeva M., The Interdisciplinary Paradigm of Tribology, Journal of the Balkan Tribological Association, Vol. 14, № 4, 421-430.
[5] Manolov N., M. Kandeva, M. Daneva, Идеята за атома в общонаучен контекст, Сб. доклади на 24 научно-технологична сесия Контакт 2009 „Интердисциплинната идея в действие", София 2009, ТЕМТО, с. 8-23. (The idea of atom in general scientific context, 24th Science-Technological Session "Contact 2009", Sofia, TEMTO, 2009)
[6] Manolov N., M. Kandeva, Обща трибология, „Св. Иван Рилски", С., 2004 (Overall Tribology, Sofia, 2004)
[7] Kandeva M., N. Hristov, N. Tonchev, E. Assenova, Tribological Study of Cladded Bimetallic Coatings,17 International Colloquium Tribology, Esslingen, 2010

Manuscript received by Editorial Board, May 24th, 2010