

CONTRIBUTIONS TOWARDS THE CONCEPT OF METAL CUTTING TRIBOSYSTEM

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ABSTRACT

The systemic approach of tribological processes involves a global vision and in the same time a vision specific to each type of process. Within a tribosystem a series of tribological phenomena take place, which will grant the system's outputs (machined surface quality, absorbed energy etc.) with values in direct dependency with the phenomena. Metal cutting tribosystems have a certain tradition in Romania. The definitions given by different authors to the notion of tribosystem are presented in this paper in a very succinct way. The concept of metal cutting tribosystem has at its core the metal cutting coupling which in turn is defined by means of basic couplings. A tribosystemic structure oriented on single- and multi-point contact tools as well as on abrasive ones is being proposed. Taxonomy in this direction is much needed.

KEYWORDS: tribosystem, metal cutting coupling, systemic approach.

1. INTRODUCTION

The cutting processes involving interface components – the tool, the workpiece and the chip – trigger the most complex contact situations. The contacts depending on variables, on complex and constant factors have an influence over the tool life as it is defined in different standards. This is a financially relevant outcome for the normal user. Yet, there is an open issue for the structuring of the phenomena, for the technological dependencies of phenomena occurring at the tool-workpiece, tool-chip interface, and so on. All these aspects require a complex, contextual, organized and systemic approach. The cutting process implies contacts which deal with friction, lubrication and wear. These variable contacts together with their dynamic and physical characteristics are tribocontacts.

The cutting process regarded as a system is marked by inputs and outputs. Naturally, the tribocontacts subjected to the input and output variables, generate the tribosystem. The overall approach of a cutting system is considered to be the approach of the cutting tribosystem.

Astakhov states in [2] that in 1998 he introduced the "system concept". According to this concept, the cutting operation is considered to run within a system made up of the tool, the workpiece and the chip.

This holds true for the English countries. In Romania, the concept called "cutting tribosystem" was approached starting with 1991 [10], [11], [12], [14].

The cutting process is defined by Astakhov [2] as being a process of distortion taking place in the structure of the cutting components. Onto these components an external energy is being exerted through the system triggering a purposeful fracture of the layer that is meant to be removed.

The development of the "cutting tribology" field, revealed in scientific work papers and topic-related books, has led us to resuming the issue concerning the definition of the "metal cutting tribosystem" concept.

The systemic approach of phenomena and tribologic processes lead to the advancement of the concept called "tribomechanical system". According to Czichos [7], "a system is a set of elements interrelated by structure and function".

The systemic approach allows a wholesome and structured object-oriented processes investigation.

2. THE TRIBOSYSTEM. THE METAL CUTTING COUPLING

The tribosystem in general and consequently the metal cutting tribosystem is considered [7] to be made

up of a steady tribo-element, a mobile one, an interposing material and a work environment. In the process complexity, cutting accompanied by tribologic phenomena occurring at the level of the tribocontacts formed during the cutting process. The generic definition of the metal cutting tribosystem is proposed to be “the overall running aspects of a cutting process exerted through interconnected elements, structure, work parameters and outputs.”

According to the type and peculiarities of the metal cutting process, the tribosystem will inherit the specificity of the process.

The cutting process involves several tribocontacts between the tool and the workpiece and between the tool and the chip respectively. In the same line with STAS 8069/87, the tool-workpiece aggregate make up a “metal cutting coupling, consisting of several basic couplings”.

From the classical approach point of view, the cutting phenomena may be regarded at the tool-chip interface level, respectively tool-workpiece interface level, but also under some other influencing elements, which according to the definition given above, are part of the metal cutting tribosystem [1], [2], [3], [8], [13], [16], [19].

Finally, the cutting tribosystem calls for a merging point between the cutting tribology study at the level of workpiece-tool-chip interfaces and the cutting tribology at the general level of the whole cutting process with all the constant and variable inputs.

The tribosystemic approach of technological processes and the tribomodelling was developed in Romania by professor Crudu and his team [4], [5], [6] and there are several tracks of further development, including the metal cutting field.

2.1 On the metal cutting coupling

In the cutting process, the triboelements – workpiece, tool, chip – materialize different tribocontacts. Relating the forces and stresses at the

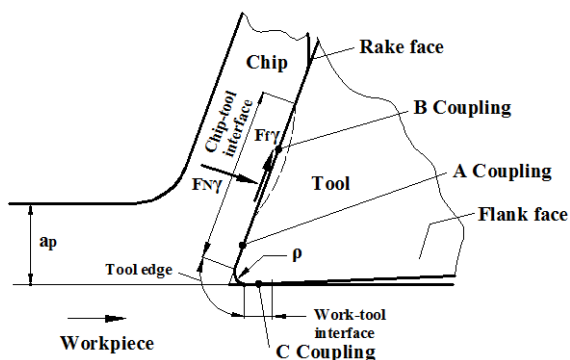


Fig.1. A,B and C Couplings [adapted by 3]

level of tribocontacts with the entire cutting process takes us to the shaping of the “metal cutting coupling”, as one with particular features for metal cutting with single-point, multi-point tools or abrasive ones.

The topic-related references [2], [18] tackle the issue of contacts at the level of tool – chip and tool - workpiece interface respectively.

The tool-chip interface is commonly rendered as being the contact area between the chip and the rake face, having a certain length which will favour specific tribologic phenomena. Fig.1.

The tool – workpiece interface is rendered as being the arc shaped contact area between the flank face of the tool and the workpiece connected both with the workpiece rough area as well as with the machined one. Between the two areas described above a transit area exists. According to [18], this interface is present both on the major cutting edge and on the minor cutting edge. Yet, [2] advances a model which takes into account only the interface at the level of the major cutting edge.

Considering the tribocontacts and the basic couplings as ideal contact situations, which subsequently change locally, the particular elements of the metal cutting coupling will be tackled for the ideal circumstance and at the level of real “evolution”.

A coupling

At the level of tool-chip interface (fig.1), the wear of the rake face appears at a distance KF from the actual tool cutting edge. This KF area between the cutting edge and the onset of the crater wear makes a surface coupling bearing specific features: continuous adherence, high temperatures with a certain particularity regarding the “flow” of the material.

B coupling

According to fig.1, between the tool rake face in the area where the crater wear forms, and the chip, the tool–chip interface takes shape, as a contact coupling between two surfaces.

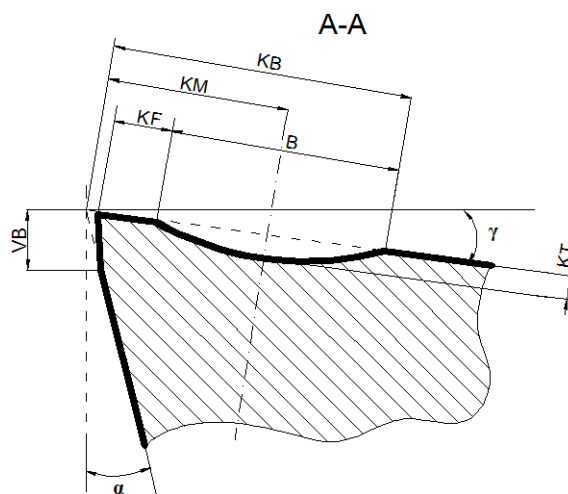


Fig.2. Detail on B coupling

Kragelsky states [9] that this coupling occurs in the region where the crater wear forms – fig. 2. This coupling is defined by normal and shearing stresses. The wear types from this area will perpetually reshape the coupling geometry at the chip–workpiece interface.

Fig. 3 [3] displays the frictional behavior (on the tool rake face) for the A and B contact couplings for the orthogonal cutting case with a continuous chip and no built-up edge. Two areas are present at the contact level: the sticking area and the sliding area.

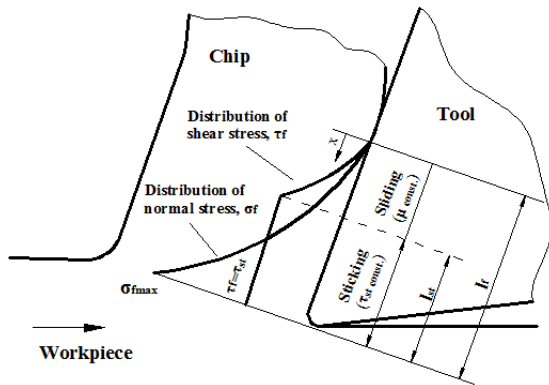


Fig.3. Detail on the state of stresses on the rake face [3]

The adherence area, distinguished through extreme temperatures, is characterized by the adherence of the workpiece material, followed by its gradual removal (A coupling). After leaving this area, alongside with a drop in the chip temperature, the adherence phenomena between the tool and the chip disappear. Next, there is a “tougher” contact in the sliding area which will take to the shaping of the crater wear. This B coupling is relevant only to chip–rake face contact, limited to the area of crater wear.

We can state that at the tool–chip contact level two contact areas occur with different behaviour conditions, areas which generate two surface couplings. Each of these surface couplings present

technological specificity (ongoing adherence in conditions of high temperatures and sliding area with rough wear effects).

C coupling

The tool flank face and the machined surface of the workpiece (named by some authors [2], [3], [18] tool-workpiece interface), in the area where the flank wear occurs (VB), right after the start of the cutting process, makes up a contact coupling between two surfaces. According to Astakhov [2], the real contact between the tool flank face and the workpiece is displayed in figure 4.

The contact between the two surfaces derives from the elasto-plastic nature of the workpiece’s deformations that result from applying cutting forces and thus leading to normal (F_{Na} , F_{Ny}) and shearing components (F_{fa} , F_{fy}).

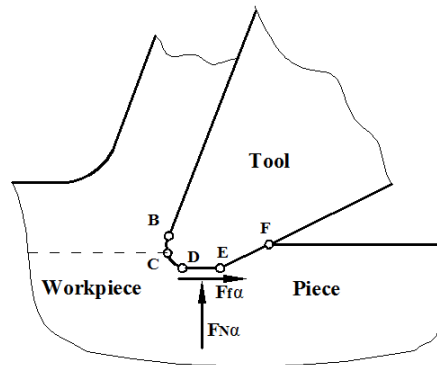


Fig.4. Detail on C coupling [adapted by 3]

D Coupling

The cutting tools have a major cutting edge and a minor cutting edge, respectively a major lead angle and a minor lead angle. The tool tip’s radius at the incidence point of the major and minor cutting edges will come under a linear contact/r radius arc – fig.5.

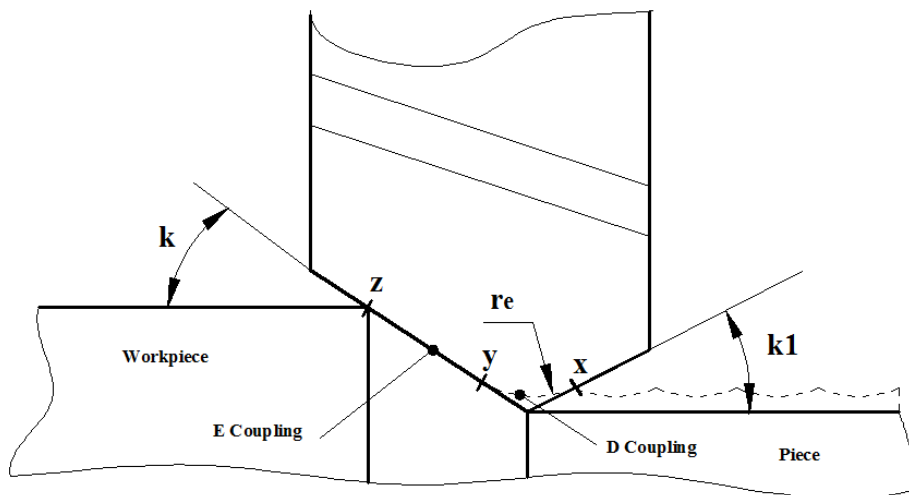


Fig.5. D and E Couplings

E Coupling

The initiation of the cutting process brings about a linear contact coupling between the major cutting edge and the workpiece, which holds on throughout the operation and favours the chip formation, triggering the other contact couplings.

The individual analysis and tribomodelling of each coupling in specific conditions allows the specification of phenomena occurring along the cutting process. The tribomodel structuring will make way to new wholesome approaches of the cutting process, especially in relation with tool wear.

The basic couplings derived from the cutting process are instantaneous. It can be assumed that one of the components is constantly the same (the tool), and the other is momentarily different from the perspective of the physical uniqueness (the workpiece).

The five basic couplings outline what we are forwarding under the name of metal cutting coupling.

2.2 The cutting tribosystem

According to Czichos [7], a tribosystem is defined by:

- structure – the structural elements;
 - relevant properties;
 - special relations among the structural elements;
- inputs (X) and outputs (Y);
- system functionality, consisting of turning the input into output, by means of a transfer function.

In the case of a metal cutting tribosystem the functionality of the system relies on the transfer function which shapes the cutting and other cutting specific functions.

In this context, figure 6 submits the proposal of the generalized cutting tribosystem, having the “*metal cutting coupling*” as main structural component.

V_s – shear velocity (m/min);

V – cutting speed (m/min);

V_1 – velocity of the chip relative to the tool rake face (m/min);

F_c – cutting force (N);

τ_y – yield shear stress of the work material (MPa);

A_c – cross-sectional area of the chip (m²);

μ - mean friction angle at the tool-chip interface (°);

γ – tool rake angle (°);

ϕ – shear angle (°);

t – tool life (min);

θ – cutting temperature (°C);

a_α – the influence of α angle over the outcome of the cutting process;

a_γ – the influence of γ angle over the outcome of the cutting process;

a_{toolm} – the influence of the tool’s material over the outcome of the cutting process;

a_{wkpm} – the influence of the workpiece’s material over the outcome of the cutting process;

$a_{\text{cut.liq}}$ – the influence of the cutting liquids over the outcome of the cutting process;

a_s – the influence of cutting feed over the outcome of the cutting process;

a_{ap} – the influence of the cutting depth over the outcome of the cutting process;

a_v – the influence of the cutting speed over the outcome of the cutting process;

a_{env} – the influence of the working environment over the outcome of the cutting process;

n – constant;

n_4 – constant;

C – constant.

According to fig.6 the proposed model for the metal cutting tribosystem is organized on 4 levels: structure, relevant properties, specific relations between the parameters of the structure’s elements and the system’s functionality. Within the metal cutting tribosystem the metal cutting coupling defined above takes the most important place. Its nature (single-point, multi-point, abrasive) will lead to different typologies of structure and approach regarding the metal cutting tribosystem. Another tackling concerns the type of cutting process for the same cutting tool type (ex. for single-point cutting tool there are the turning process, shaping, mortising etc.) which behaves in different ways.

The interposing material embedded in the structure is to be considered as being the material introduced in the tribosystem by means of a technical system (liquid, lubrication gas or immersive/hydro cutting). This will separate it from the working environment (air with its composition) which has complementary or even similar influences with the interposing material.

The relevant properties developed within the metal cutting tribosystem, properties concerning the chip removal phenomenon, friction, lubrication, cooling, cutting improvements, are directly dependent on the structure and specific relations between the parameters of the structure’s elements.

These relations define the main interdependencies which if to pass through optimization processes might lead to mono or multi criteria bases. They may also lead to efficiency, better results in obtaining high quality machined products, etc. (ex. a_α, a_γ - the influence of α, γ angles over machined surface roughness, a_s - the influence of feed over machined surface roughness, etc.).

The system’s functionality will have at its base elements related to models of chip formation (Merchant), to workpiece material behavior with respect to the cutting process, process energy and tool life represented by Taylor’s equation. The cutting temperature’s influences over the outcome of the process are also present in the generalized approach.

The cutting process can turn the input of constant value into variable output with respect to

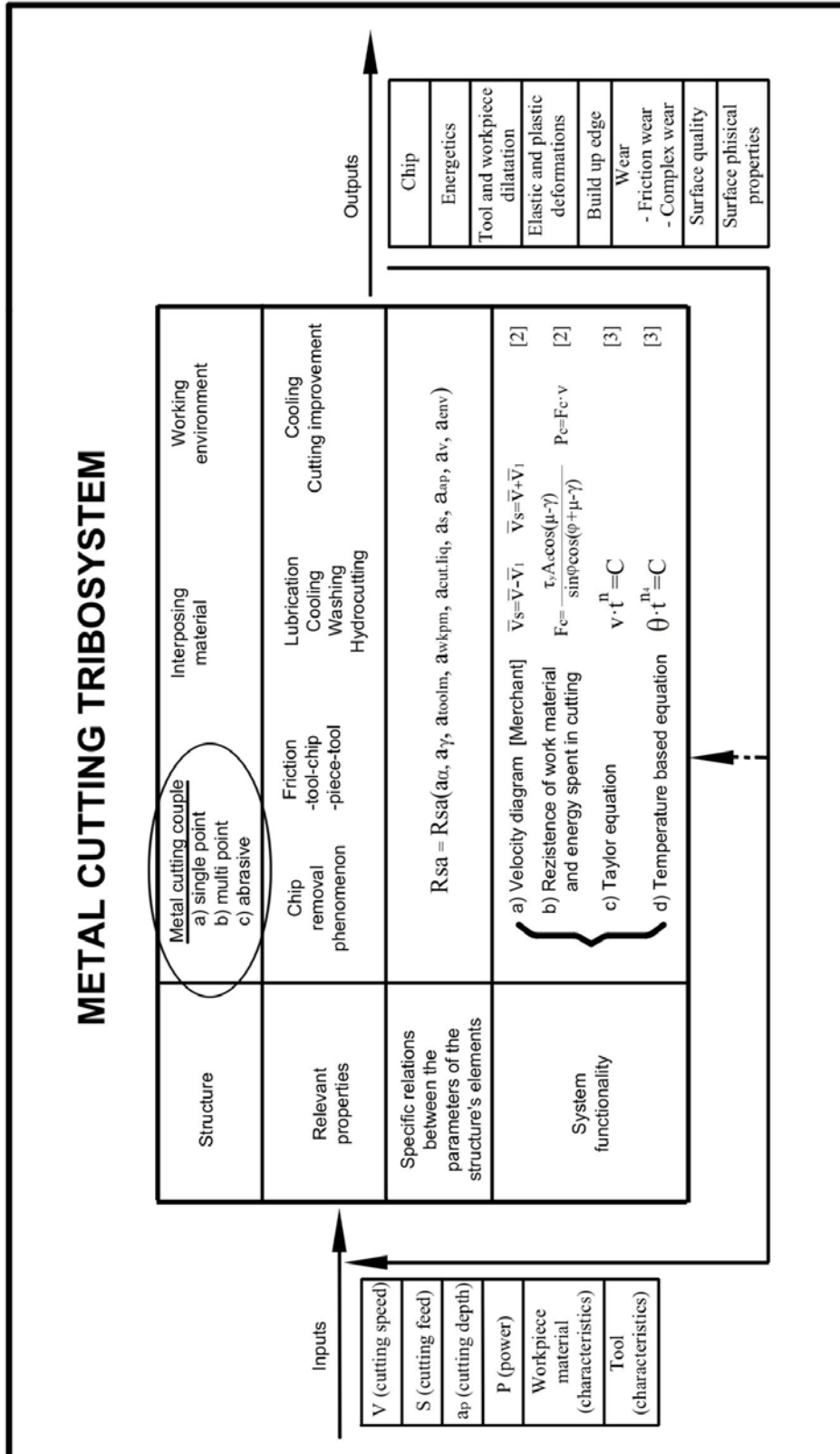


Fig.6 Proposed model for the metal cutting tribosystem

exerted by the wear over the output is grounded on the wear criterion defined by Kragelsky [9] as the amount/level of wear at which the tool should be put out of use. This definition cannot be considered a sufficient one. The wear criterion must not be mistaken for the tool life in what regards the cutting capacity. The tools can have cutting capacity, but fail in reaching accuracy (profiled tools) or they can have cutting capacity and accuracy, but they require high energy consumption or the machine can't withstand the load the tool is able to.

The metal cutting process regarded as a cutting tribosystem implies the wholesome approach of all the inputs within the tribosystem, as well as the analysis and the exclusive development of the phenomena within the cutting process influencing the outputs: chip, energetics, deformations, etc. This tackling will allow the present major issues in cutting science and tribology to be analyzed and described.

3. CONCLUSIONS

If the tribologic approaches of the cutting process occur at the level of tool-workpiece and tool-chip interface, a model of complex analysis for the metal cutting coupling is forwarded, through the study of the basic couplings which make it up, with their particular features.

The presently advanced tribosystem model benefits from the approach of the cutting tribology at the level of basic couplings of the tool-chip and tool-workpiece interfaces, merging and integrated in the tribologic approach of the entire cutting process, with constant and variable inputs.

It is required to study the wear criteria of the cutting tools in tandem with the tool life.

The newly-appeared technical field of “*metal cutting tribology*” is worth studying as an outlining experience with elements borrowed from tribology and metal cutting, as well as with its own paradigms.

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