# THE CUTTING TRIBOSYSTEM IN THE CURRENT ENGINEERING CONTEXT

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**Abstract:** Tribological phenomenon play an important role in the materials processing, especially in cutting operations. The purpose of this scientific paper is to present a series of modern concepts and perceptions in the evolution of the cutting tribosystem. The scientific research carried out in recent years, based on a large number of experiments, has shown that tribological phenomenon and processes occurring in the superficial layer have an interdisciplinary character. Therefore, the emergence and development of the finite element analysis method is closely related to the evolution of the computing technique. Current research is geared towards creating and testing new types of finite elements that meet the new requirements of today's engineering applications. In this respect, the progress made by software companies in the field of finite element analysis is particularly high.

**Key words:** finite element analysis, research, concept, simulation, cutting tribosystem

## 1. BASIC CONCEPTS IN THE APPROACH FIELD

Tribological phenomena play an important role in the materials processing, especially in cutting operations. The systemic approach of tribological phenomena and processes led to the introduction of the tribosystem concepts, tribomechanic system also reaching standardization according to DIN 50320.

In tribology, the first who introduce the notion of system was Czichos in 1978 and then Astakhov in 2006. Thus, based on this approach, it is considered that the cutting operation takes place within a system made up of the following elements: the cutting tool, workpiece and the chip. In his paper, Godet (Godet et al. 1982) mentions: "The simulation can be compared to a black box with initial conditions and results that are transposed to an application with a minimal number of interpretations. The difficulty is to carefully design this black box." The scientific research carried out in recent years, based on a large number of experiments, has shown that tribological phenomena and processes occurring in the superficial layer have an interdisciplinary character.

Regarding the cutting conditions of cutting fluids, a number of studies and researches have been identified by various authors such as Yang and Lo (2004) who assert that usually the methods of lubricant analysis are applicable only in in the case of flat or axisymetrical deformations; Patir and Cheng (1979) which, considering surface roughness, proposed an average of the Reynolds equation for analyzing the flow of lubricants, and Wilson and Wang (1984), who researched the theoretical model of thicker film lubricant for a simple deformation process of cylindrical or spherical stripes. In the case of lubrication analysis, a model of the finite element is elaborated using Reynolds equations that regulates the flow behavior of the lubricant stream. The finite element model can treat 3D the metal deformation process, being a net superior to other conventional models such as the decomposition of Reynolds equations into basic equations. Sun and others (1987) combines the finite element method applied to deformation of the sheets with the Wilson and Wang (1984) research related to the intake zone analysis for calculating the thickness of the lubricating film at the edge of the contact surface. Hsu and Wilson (1994) combine analyzes of the inlet and work area with the finite element method in the elastoplastic field of thin plate deformations, both with and without rigid bending.

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The expected results of the lubrication film thickness are consistent with the experimental data developed by Wilson and Hector (1991). In the case of total lubrication, the discrepancy between film thickness and tangential frictional tension is very small. However, it is possible that the roughness effect cannot be ignored in the case of mixed lubrication when there is a high contact stress. The finite elements analysis of the lubrication is much more precise and advantageous than the classical research of characteristic equations. This analysis can be applied to 3D problems with complicated geometries.

## 2. EVOLUTION, PAST, PRESENT AND FUTURE

Starting from what Wayne Hamman, director of production and manufacturing of FORD, Computer Integrated Manufacture and Engineering, that "The only way to reduce costs and manufacturing time is to eliminate physical prototypes by making virtual prototypes," can be said without fear of error, as Cătălin Alexandru (Alexandru, 2002) that the giant steps that mankind has gone through over the last decades is largely due to the computer assisted of all economic and social activity.

The emergence and development of the finite element analysis method is closely related to the evolution of the computing technique. Current research is geared towards creating and testing new types of finite elements that meet the new requirements of today's engineering applications. In this respect, the progress made by software companies in the field of finite element analysis is particularly high. The finite element method was applied for the first time in the calculation of resistance structures. Due to the generality of this method, it has expanded rapidly in almost all areas of engineering computations based on physics-mathematical computational methods. The formulation of the finite element method is based on the formulation of the extreme conditions that some of the sizes involved in the phenomenon studied must satisfy them. It is therefore a numerical method with a wide range of applicability that enjoys the benefit of a simple formulation. Simulation based on finite element analysis reduces the need for costly physical prototypes. Using virtual prototypes, it provides data on product behavior from the very first design phases. It is much easier to modify the virtual model than the physical prototype to achieve the desired result.

## 3. THE FINITE ELEMENT ANALISYS IN THE CUTTING TRYBOSISTEM

In order to understand the mechanisms for cutting materials, special attention should be given to development of simplified models. The representative researches by Piispanen (1948), Merchant (1945) and Oxley (1965) focused their study on the relationship between the cutting angle, the tooling angle of the tool and the friction between the tool and the blank. Machining is an irreversible process, which at various temperatures includes large plastic deformations. Mechanically, regulating equations are needed for chip formation and separation, cutting forces, cutting temperatures, tool wear, and so on. However, the solutions of displacements, velocities, stresses, stresses and temperature limits in the cutting process cannot be easily obtained because large deformations and high temperatures lead to a high nonlinearity and time dependence of the process (Benson, 1989).

Strenkowski and Carroll (1985) introduced a chip separation criterion based on plastic deformation, simulating by the start the chip formation, and discussed the effect of this criterion on simulation results. They found that the change in the effective deformation threshold in the range of 0.2 to 1.0 had a small effect on the geometry of the chips and the tool forces. However, the variation would significantly negative affect the residual stress of the machined surface of the workpiece. In general, an increase in this threshold leads to a residual stress in a much larger area.

In his article, Komvopoulos with Erpenbeck (1991) investigated the edge effect using the deformation state of the cutting model and applied the separation criterion, in which case it is assumed that when the distance between the cutting tool and the finite element node in the cutting zone reaches a certain value, the node will be separated from the workpiece material. Z. Lin and Lin S. (1992)

introduced a chip separation criteria that uses as argument the energy emitted by deformations in the study of chip geometry, surface tension, and the temperature distribution on the chip, tool and cutting forces.

## 4. SOLUTIONS PROPOSED IN THE RESEARCH

Based on the consultation of the specialty bibliography, it was found that two numerical formulations were used extensively in the finite element simulation of solid deformation processes: the Lagrange formulation and the Euler formulation. The FEA concept of Arbitrary Lagrange-Euler's approach was initially designed for fluid mechanics application and then adopted for state solid mechanics (Harber, 1984).

So far, very few attempts have been made to perform numerical analysis of the complete lubrication process in the metal deformation process, such as extrusion, forging, stretching, rolling, stamping, etc. This is due to the fact that usually the lubrication analysis methods are applicable only in the case of flat or axial deformations. Deformation of metals depends not only on the properties of the material, but also on the friction between the tool and the blank, and the surface quality is also affected by the applied lubricant. In the case of a thicker lubricant film, a matte surface will result from the fact that during processing, the workpiece cannot be sufficiently constrained. If the lubricating film is too thin, there will be a direct metal contact on the metal, which will lead to defects on the surface of the piece. Therefore, the presence of a suitable lubricating film of adequate thickness between the contact surfaces in the deformation process of the metal effectively influences the increase in plasticity, reducing the wear and improving the quality of the processed surfaces. In order to suitably choose the lubricant and the optimal thickness of the film, it is also necessary to consider the theoretical aspects of lubrication. Reynolds conventional equation is proper to analyze smooth surface lubrication problems; but this cannot be applied to plastic deformations of metals where the surface roughness has a significant influence on the lubricant transport.

Taking into account surface roughness, Patir and Cheng (8978) proposed an average of Reynolds equation for analyzing the flow of lubricant. This has been successfully applied to roller bearing systems. Shortly after the two mentioned authors, hydrodynamic lubrication was also developed to deform the sheets. A first attempt was made by Wilson and Wang (1991) who researched a theoretical model of the thicker lubricant film for a simple deformation process of cylindrical or spherical punches. The two have divided the lubricant film into two zones: the work area located near the center of the fist where the pressure coefficient has a negligible influence on the lubricant flow; and the intake zone - adjacent to the work area, which controls the lubricating film formation. Sun (1978) combines the finite element method applied to the deformations of the sheets with Wilson and Wang (1984) research on the intake zone analysis for calculating the thickness of the lubricant film at the edge of the contact surface. The requests for this analysis are consistent with the experimental measurements. In addition, Hsu and Wilson (1994) combine in-zone and work area analyzes with the finite element method in the elasto-plastic field of thin plate deformations, both with and without rigid bending. The action of compressing and altering the curvature of the plates was also taken into account in the hydrodynamic lubrication analysis. The thickness of the lubricating film in the intake and working areas can be determined using the results of the tensile element analysis as inputs for the grease analysis. The predicted results of the lubricant film thickness are consistent with experimental data developed by Wilson and Hector (1991).

All of the above is based on the decomposition of the Reynolds equation into two differential equations, which are characteristic of the position and thickness of the lubricant film along the entire surface of the piece. The information about the nodes used in the analysis of the finite elements in the plastic deformation of metals cannot be adopted directly by the lubrication analysis.

This takes into account the commitment of a certain degree of interpolation and the occurrence of measurement errors that are expected. However, to avoid such errors, the authors mentioned above suggest that tribological coding nodes of deformation must have the same interface and instrument tool, despite the deficiencies reported by Schmid (2002). All finite element encodings require a high density of nodes to capture all variations. The best option would be to use the same node system. The authors Booker and Huebner (1972), Taylor and O'Callahan (1972), LaBouff and Booker (1985), Kumar et al. (1990), Kumar and Booker (1991), and Boedo and Booker (1997) developed finite element formulas for the lubrication problem in the bearing rotor. Hu and Liu (1993) combined the analysis of the finished hydrodynamic lubricant with the plasticity analysis in the rolling process. The influence of surface roughness on the lubricating film is included in the model, while the compression effect is more inconsistent in the plastic deformation process is not taken into account until the rolling process is a stable operation. It is therefore essential to address these issues in detail. In the total lubrication mode, the surfaces of the tool and the workpiece are not in contact and, in general, the interaction of the two is completely determined by the lubricating film. An equation for adjusting the lubricating film is that proposed by Patir and Cheng (1979):

$$\nabla\cdot\left(\frac{h^3}{12\eta}\cdot\phi^p\cdot\nabla_p\right)=\nabla\cdot\left(h_t U+\frac{R_q}{2}\cdot\phi^S\cdot V\right)+\frac{\partial h_t}{\partial t} \quad (1)$$

where:

$\eta$ - lubricant pressure;

h - nominal separation between surfaces (defined as the sector of separation between the median planes of the undeformed area);

h1 – the average thickness of the lubricant film (defined as the volume of lubricant in a small region divided by the interference area);

Rq – the composite roughness of the RMS of the tool and the workpiece;

U –medium speed;

V – the relative speed between surfaces;

$\phi^p$ - the pressure factor of the lubricant flow;

$\phi^S$ - the tangential strain on the fluid stream.

Physical, $\phi^p$ and $\phi^S$ characterizes the flow effects caused by roughness of the parallel and transverse surface of the movement. The value of h is equal to h1 in the total lubrication mode. In the total lubrication regime, the expression of hydrodynamic friction must be modified taking into account the roughness effect. When the contact surface of the contact surface approaches zero, friction contributes totally to the viscosity of the fluid, which can be calculated according to the procedures of Patir and Cheng (1979). According to Hsu and Wilson (1994), the lubrication zone can be divided into two zones: the entry zone and the working area. The lubricant is trained in the entry area and enters the working area during the plastic deformation process.

## 5. CONCLUSIONS

Tribological phenomena play an important role in the processing of materials, especially in cutting operations. Due to the fact that the technical and economic feasibility of a product or process can be determined by wear and tear, tribological knowledge can help increase competitiveness in the manufacturing industry and minimize energy consumption and consumed resources. The emergence and development of the finite element analysis method is closely related to the evolution of the computing technique. Current research is geared towards creating and testing new types of finite elements that meet the new requirements of today's engineering applications. The generality of the method gives it the advantage of adapting with simple changes to the most complex and varied issues such as linear and nonlinear problems, statistical and dynamic demands, etc.

Current trends in the study of the main factors that influence chipping are to analyze the cutting process using the finite element method. The numerical approach using the finite element method has become the mainstream of processing analysis after its development. Based on the consultation of the specialty bibliography, it was found that two numerical formulations were used extensively in the finite element simulation of solid deformation processes: the Lagrange formulation and the Euler formulation. The ALE technique has been developed primarily to take advantage of the two traditional techniques and to avoid their disadvantages, using each technique if it is advantageous to do so. Adaptive Discretization within the Finite Element Analysis method can significantly reduce distorted elements, stresses, stresses, and temperatures in the surface layer, improving mesh quality.

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