A study of fluid flow simulation in convergent–divergent nozzles

I Olaru

"Vasile Alecsandri" University of Bacau, 157 Calea Marasesti, Romania

E-mail: ionelo@ub.ro

Abstract. A study of geometry nozzle is particularly important in optimizing the quantity of coolant in terms to minimize that quantity or coolant can be used for lubrication of machines moving parts. Coolants can be from the simplest (water, air) as well as a mixture of liquid (emulsions) to achieve a good cooling in function of temperature that develops in the area concerned. The study from this paper proposes an analysis and a simulation of flow through the convergent-divergent nozzle type to optimize them and to use a minimum quantity of coolant or lubricant. This study is focus on the analysis of cooling systems for cutting processes on machine tools.

1. Introduction

In industrial applications, coolants are used for different working situations. The cooling fluid is sent in the area to be cooled in particular by means of nozzles. A nozzle is generally a device that increases the velocity of a fluid flow at the expense of this pressure, the flow of fluid through nozzles may be regarded as adiabatic expansion. The nozzles have a special geometry to send a small amount of liquid but to have a good cooling effect [1].

Cooling capacity is a property of liquid cooling/lubrication and is due to evacuation of heat generated in the cutting process, helps to reduce of the temperature of the tool, of the piece and the whole cutting system.

With lubrication fluids are reduced friction forces between the chip and rake face and between the seating face and the machined surface. Cutting fluid is drawn on the chips surfaces with high adhesion forces, forming a film with large surface pressure resistance. Washing effect of cooling liquids, lead to the removal of small chips, metal dust, etc. [2].

Cooling liquids or lubricants used equation a special attention, a greater quantity of liquid consumed can be harmful environment, a larger quantity of fluid can generate high production costs, depending on their chemical composition and reaction with various heated zones of the process may be harmful to the operator [3].

Coolants must have the following properties: does not affect sealing parts of machine tool, to be stable and compatible with the materials used and the type of processing, should not be toxic, and not smoke in contact with cold zone and to be with low flammability [4].

The cutting surfaces lubrication can be achieved under continuous hydrodynamic film, semi-liquid friction and friction limit. In hydrodynamic lubrication regimes, the sliding surfaces are separated by a thick layer of fluid and are sufficiently high to prevent the contact between both surfaces [5].
In industrial applications are used the following types of coolants and lubricants: water, air, oil, water-immiscible oils, fluids emulsifiable in aqueous solutions or organic compounds or inorganic and suspensions or solid lubricant pastes.

The emulsion is a system consisting of two immiscible phases or partially miscible with one phase dispersed in the other state. Water and oil phases can form type of emulsions with water as mainly fluid and oil as a secondary fluid or oil as mainly fluid and water like secondary fluid, however only the main fluid water emulsions can dilute the oil. Appropriate nozzle geometry could use a minimum quantity of coolant that can accurately be sent to the area to be cooled [6].

2. Design of nozzles
For simulations in this paper were considered four types of nozzles: the first type serves as the output surface of the working fluid a series of small diameter holes. In figure 1 was rated nozzle number 1 and is used mainly when cooling fluid with low viscosity. In the case of using a fluid with high viscosity or emulsion can be used nozzle geometries denoted by 2 and 3 in figure 1. The nozzle with number 4 is simple and can be found on many types of machine tools [7].

Figure 1 shows the geometric dimensions for each nozzle, nozzle number 3 is a venture type being of convergent-divergent type, nozzle number 1 and 2 only shows a flattening of frontal area to be able to direct the fluid jet as accurately in the area to be cooled and to be lubricated if is necessary.

3. Fluid flow simulations
The simulations are performed using a specialized program with finite element which analysis the flow through the different nozzles with different operating parameters and different geometries of a convergent-divergent nozzle. These simulations can be compared to real working conditions on the machine tool system.

Mathematical model can begin from relation between pressure and velocity of fluid, in the nozzle the distances have small values the forces of gravity can be neglected compared to inertial forces and pressure forces and have a Bernoulli expression for the fluid [8]:

Figure 1. Different type of nozzles used for simulations.
\[ \frac{v^2}{2g} + \frac{p}{\gamma} + z = \text{Const.} \]  \hspace{1cm} (1)

In what follows we have presented in figure 2 velocity distributions along the nozzle noted down for number 1 [9, 10].

**Figure 2.** Velocity variation along the nozzle no. 1 for two working fluids: a. water; b. air.

As can be seen in figure 2 the velocities of the working fluid increases in area in which we have holes for guiding the fluid jet. Velocities values are as is normal smaller for water than for air.

**Figure 3.** Velocity variation along the nozzle no. 2 for two working fluids: a. water; b. air.

For simulations in this paper were chosen the two fluids due their simplicity, to their low cost and their different properties. Figure 3 presents diagrams velocities for nozzle number 2.
Figure 4. Velocity variation along the nozzle no. 3 for two working fluids: a. water; b. air.

For this type of nozzle (figure 3) been renounced at the holes in the outlet of the fluid, practically in this area is performed only a flattening of the jet of fluid this will record higher values of velocities in this area.

Figure 5. Velocity variation along the nozzle no. 4 for two working fluids: a. water; b. air.

Figures 4 and 5 show a convergent-divergent nozzle and a simply convergent nozzle used for cooling with a wide range of coolants because it is not important the working fluid viscosity.

Simulations were performed using SolidWorks software, initial geometries were established for all four nozzles studied in this paper and all kinds of nozzles have main dimensions similar to be able to analyse better them. As input parameters for simulations we used the two coolants with their physical features, for all types of nozzles have be chosen 3 bar at input pressure, and at the exit of the nozzle was set the atmospheric pressure because the fluid jet is open to the atmosphere.

Figure 6 presents the variation of the velocities charts in usable length of nozzles, for better illustration were grouped by the working fluid used.
The nozzle 3 convergent-divergent type shows a graph a bit different from the other three charts because it has the middle area where the fluid velocity increases with decreasing pressure, which is more pronounced for water. The air does not have the same friction forces with wall, the chart resulted approximately as for other types of nozzles, registering an increase of air velocity in the exit area.

With computer software could simulate the flow inside the chosen nozzle were not taken into account other elements which are not relevant to the study such as: working fluid temperature, convection phenomena of fluid and wall nozzle, conduction phenomenon trough material, was considered a perfect fluid, wall roughness was neglected and load loses of nozzle because it has a relatively small length.

4. Conclusions
After simulations for several nozzle geometries can be concluded from the analysis of flow in the nozzle is very important, following this analysis can optimize the size and shape of the nozzles so that the cooling fluid to be distributed more efficiently in the processed area.

A special importance presents the choice of a cooling fluid depending on the geometry of the nozzle so as to eliminate hydraulic blockages that may arise and can lead to increased fluid pumping power and thus to a higher consumption of lubricant or cooling fluid.

Correct distribution of the fluid in the area leads to a lubricant saving, it no longer wasted, it is recognized that some coolant can be quite expensive, so choosing the right nozzle depending on the physical properties of the lubricant is also important.

Fluid jets are used in many industries; this paper aims to study the jets of fluid that pass through the nozzles particularly used in machine building industry, with those type of nozzles is performed cooling of machining zone. In this sense have been made many specific studies to research how fluid leaves the nozzle and how it wet in the processing area to achieve an equation cooling when is used a small quantity of lubricant.

Study the way in which the fluid flows through the nozzle by computer simulation. In mechanical cutting process is very important to study the cooling fluid jet using minimal quantity of fluid.

This analysis brings more clarification on the cooling fluid flow inside the nozzle and can be analyzing charts speeds, pressure or any analysis on how the vortex flow is formed and the influence of nozzle geometry on fluid distribution in the processed area.

References
[1] Kurnosov N E and Tarnopolskii A V 2007 Air–Liquid Lubricant and Coolant Aerosols in Machining Russian Engineering Research 27(10) pp 689–691
[2] Nedelcu D-I and Olaru I 2013 Study of Cooling Parameters using Fluid Jet in Milling Process Simulation Applied Mechanics and Materials 371 (Switzerland: Trans Tech Publications) pp 524-528
[3] Ryzhkin A A, Shuchev K G, Aliev M M and Gusev V V 2008 Dissipative Properties of Lubricant and Coolant Fluid in Cutting and Friction Russian Engineering Research 28(12) pp 1243–1247

[4] Rozati A and Tafti D K 2008 Effect of coolant–mainstream blowing ratio on leading edge film cooling flow and heat transfer – LES investigation International Journal of Heat and Fluid Flow 29 pp 857–873

[5] Olaru I 2013 The Fluid Flow Simulation through to a Convergent Nozzle Journal of Engineering Studies and Research 19(2) pp 76 - 80

[6] Liu J, Han R, Zhang L and Guo H 2007 Study on lubricating characteristic and tool wear with water vapor as coolant and lubricant in green cutting Wear 262 pp 442–452

[7] Olaru I 2013 The Fluid Flow Simulation through to a Venturi Nozzle Journal of Engineering Studies and Research 19(1) pp 42 - 46

[8] Florescu I, Florescu D and Olaru I 2003 Fluid mechanics and hydraulic machines Laboratory Guidance (in romanian) (Chișinău: Editura Tehnica Info)

[9] Information on SolidWorks: http://www.solidworks.com/sw/resources/solidworks-tutorials.htm. Accessed 19/01/2015

[10] Information on SolidWorks Tutorials: http://www.solidworkstutorials.com. Accessed 23/02/2015