Design of Internally Cooled Tools for Turning

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***Abstract* – Nowadays more and more emphasis is put on the development of environmentally friendly technologies. It is well known that the use of cutting fluid or cooling liquid poses risks to environment and health. It can also increase the cost of manufacturing. This paper presents the latest developments in smart cutting tools having internal cooling. This paper unites the main researches that have been done in the field of internally cooled tools. Many proposed solutions are still at the conceptual level. This paper recognizes the concepts of internally cooled tools and gives directions for further research and discussions.**

***Keywords* – internally, cooled, smart, tool, turning.**

I. Introduction

During the cutting, due to the friction and chip deformation, high cutting temperatures occur and a tool and a workpiece are subjected to increased thermal load causing significant tool wear. It causes wear and thermal damage of the cutting tool, shortening tool life and consequently, resulting in poor surface roughness and dimensional tolerance. To reduce the cutting temperature, cutting fluid is traditionally used to remove the heat generated, decrease cutting force, and improve tool life.

Cutting fluid is also used to reduce formation of a built-up edge and increase the removal of chips from the cutting area. However, the use of cutting fluid has its disadvantages. Depending on the workpiece, the production process, and the production location, the costs related to the use of cooling lubricants range from 7 per cent to 17 per cent of the total costs of the manufactured workpiece [1]. Additionally, many cooling fluids contain harmful or damaging chemicals causing environment pollution and operator's health hazards, so strict environmental policies and health regulations have been introduced in connection with the increasing awareness of the environment and human health [2, 3]. To cope with the mentioned hazards it is necessary to operate in dry cutting mode, where no cutting fluid is used. Therefore, components and/or products can be manufactured both ecologically and economically. Dry cutting could be a solution if other obstacles would not arise. In dry cutting as a result of absence of cutting fluid more friction and adhesion between the tool and workpiece will occur.

Recently many research attempts have been initiated to investigate the possibility of avoiding the use of cutting fluid, such as using new tool materials and geometries, adding a heat pipe to the cutting tool, coating with solid lubricant, and applying internal cooling, etc. [3-7].

The most promising solution for dry cutting seems to be the use of internal cooling. Many researchers concentrate their research in this field, but still there is no concrete solution, which could be brought into industry.

This paper analyses internal cooling techniques and introduces novel solutions or concepts, on which research could be carried on.

II. Design Concepts of Internally Cooled Tools

In industry cooling of cutting tools as well as cutting area is provided still in the conventional way - cutting fluid is fed into the cutting area directly. In this cutting area certain part of the cutting fluid evaporates and the rest of cutting fluid mixes with chips. After certain time cutting fluid wears out and it cannot be used anymore.

First designs of internally cooled tools proposed the following solution: a cavity in the tool holder was made; over this cavity a cutting insert was placed; cutting fluid was introduced through the channel in the tool holder; the cutting fluid flew to the said cavity under the cutting insert; heat from cutting insert was transferred to the given cutting fluid, which in turn was pushed away from the given cavity via an outlet channel made into the holder. This is a typical scheme of internally cooled tool in turning. Fig. 1 illustrates this typical scheme of internal cooling system [8].

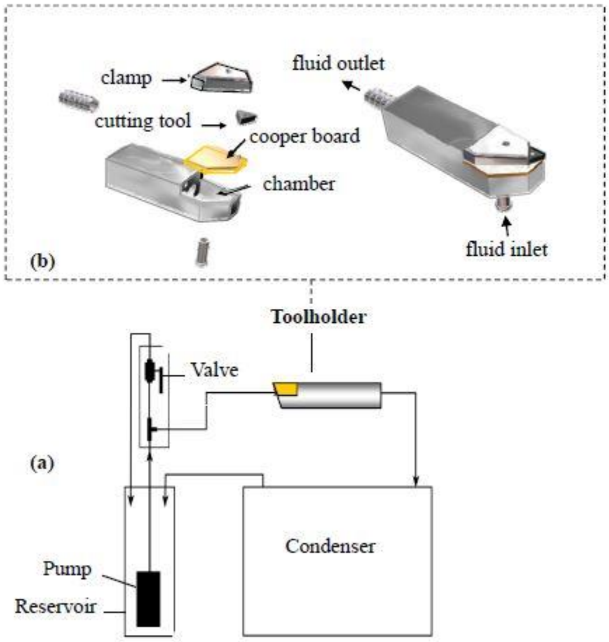

Fig. 1. Scheme of the cooling system (a) and tool holder (b) [8]

Another approach introduces a cutting tool having a cutting element such as an insert which is cooled indirectly by a micro-channel heat exchanger that is mounted against the rear face of the insert (see Fig. 2). The heat exchanger is formed with an internal cavity that receives a coolant such as cryogen. The cavity may include fins to enhance the removal of heat by the cryogen from the insert. Coolant inlet and outlet tubes are coupled to the interior of the heat exchanger to supply cryogen to the cavity. The flow rate of cryogen required to cool the insert during the given machining operation is less than 1% of the amount of standard coolant required to cool the same insert during the same machining operation [9].

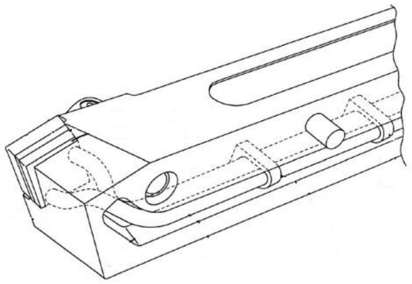

Fig.2. Cutting tool having indirect cooling solution [9]

Lagerberg [10] proposes a cutting insert having a cutting edge for chip removing machining (see Fig. 3). The cutting insert comprises a supporting body comprising a porous material forming a micro-porous structure throughout the supporting body to conduct the flow of cooling medium. The supporting body having an outer periphery including an upper surface and a side face, the supporting body being enveloped by a shell substantially impermeable to cooling medium. The shell includes a wear body disposed on the upper surface of the supporting body and forming the cutting edge. The shell has at least two openings exposing the supporting body, the first of the openings disposed remotely from the cutting edge and serving as an entrance for the cooling medium, and the second of the openings disposed at an upper end of the side face beneath the cutting edge and serving as an exit for the cooling medium to cool the cutting edge. The outer periphery of the supporting body defines an inner volume, wherein the micro-porous structure occupies the entire inner volume [10]. The given solution partly represents a concept of internal cooling, because the cutting fluid escapes through porous structure of the cutting insert into the environment. This solution does not provide complete internal cooling and cannot be considered to comply with environmental policies and health regulations. It can be considered that such tools cannot be classified as internally cooled tools.

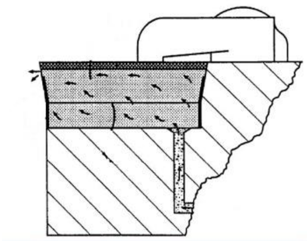

Fig.3. Cutting holder with cutting insert having internal cooling [10]

Internally cooling the tools also gives such an option as monitoring the temperature in the cutting area. Bahram Keramati [11] proposes a cutting tool having on-line monitoring system measuring the heat generation rate at the cutting edge and relating this to the condition of the cutting edge. A flow of fluid coolant contacts the back surface of the cutting tool and the coolant temperature rise is measured during the machining process. The temperature difference and its rate of rise or fall is a direct indication of the heat generation rate and is related to tool conditions such as excessive and rapid wear and breakage. In the case of inserts, coolant channels are formed in the reusable seat, and tool holder channels provide for the flow of coolant to the seat (see Fig. 4).

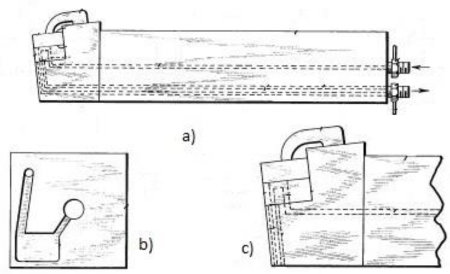

Fig. 4. a) a side view of a tool holder, seat and cutting insert modified to incorporate the on-line tool condition sensing system; b) a plan view of the coolant channel machined into the cutting tool seat; c) a partial side view of the tool holder, seat and insert, showing an alternate location of the tool holder exit channel for coolant flow [11]

Enders [12] suggests a design of a cutting tool insert that includes: a body defining a rake face, a flank face, and a cutting edge at an intersection of the rake and flank faces; and a cooling micro duct within the body (see Fig. 5). A portion of the micro duct extends along the cutting edge not more than 0.5 millimeter from the rake face, and not more than 0.5 millimeter from the flank face. The micro duct has a cross-sectional area of not more than 1.0 square millimeter. The micro duct is adapted to permit the through flow of a coolant to transfer heat away from the cutting edge and extend the useful life of the insert. Secondary conduits having cross-sectional area no larger than 0.004 square millimeter may communicate between the micro duct and the rake and/or flank face to exhaust the coolant behind the cutting edge and further enhance cooling.

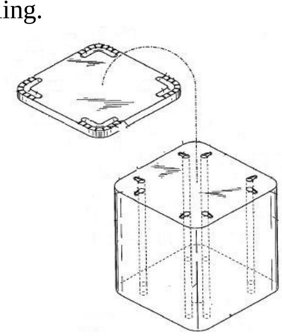

Fig. 5. Cutting tool insert having internal microduct for coolant being assembled [11]

Samir [13] describes an arrangement in which fluid dynamics is used to provide a cooling effect to a cutting tool while in use. More specifically, the cutting tool is based upon the principles that fluid expands when sent through a restricted diameter channel which concomitantly to expansion and reduced pressure also causes a markedly reduced temperature of the arrangement. A cooling element comprising a long, restricted channel arranged on the support plate in a tightly spaced continuous pattern and has an inlet for any desired cooling fluid and an outlet (see Fig. 6). Cooling fluids can be contained within the system for indefinite reuse or can be cycled through (i.e. air or water). Preferred cooling fluids are tap water or ambient air.

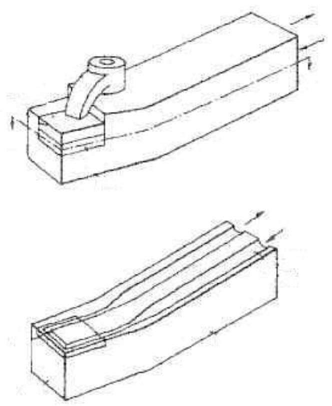

Fig.6. Cutting tool comprising long, restricted channel [13]

Another solution proposes internally cooled cutting tool which has a “bottle-cup” insert and chamfered adaptor plate as shown in Fig. 7. Two micro holes located at the adaptor corners work as the inlet and outlet for the cooling fluid. When the insert and adaptor come together, a cooling tube with triangular section will be formed for the cooling liquid to flow through [14]. The research concluded that under the same thermal boundary conditions, the simulated cutting tip temperatures of internally cooled tools are much lower than those of non-cooled cutting tools. It was also concluded that the diameter of the cooling tube has the most significant impact on the tool cooling efficiency.

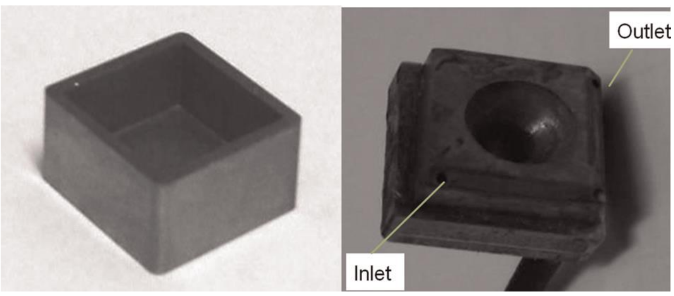

Fig.7. Internal cutting tool structure [14].

In every research on internally cooled tools it was concluded that in real cutting situations, internal cooling would significantly decrease the cutting temperature and thus improve the cutting tool life.

III. NOVEL CONCEPT OF INTERNALLY COOLED TOOL

The given publications define prior art or the known technical level and give proof that tools with internal cooling have advantages over conventional tools, therefore allowing to do successful dry cutting.

After extensive research of the known internal cooling techniques or concepts, we concluded that the field is still at the conceptual level. One of the main drawbacks of internally cooled tools with closed circuit flow is their complicated manufacturing. Another reason is non-existence of strict rules regulating the use of cutting fluids. It all can change if governments impose restrictions on the use of cutting fluids. After research of prior art we designed our internally cooled tools, especially internally cooled tools for turning. In Fig. 8 one of the concepts of internally cooled tool is shown. The tool has two part tool holder. The tool holder itself has many possibilities for improvement. Some research could be done in developing a tool holder made of different grades of material. Such a combination of materials could be used as a heat-sink.

Basically there can be two possible design solutions for internal cooling of a tool. The first one includes cooling fluid channels that are built in an insert itself. The given approach should comprise a compromise between two factors: integrity of the insert versus cooling performance of the insert. The second solution includes cooling fluid channels that are built in a tool holder (see Fig. 8 and 9). The mentioned tool has good integrity but in some conditions could not be able to provide enough cooling performance. The cooling performance can be improved by developing the channel of cooling fluid as well as increasing flow parameters of the cooling fluid (mainly pressure).

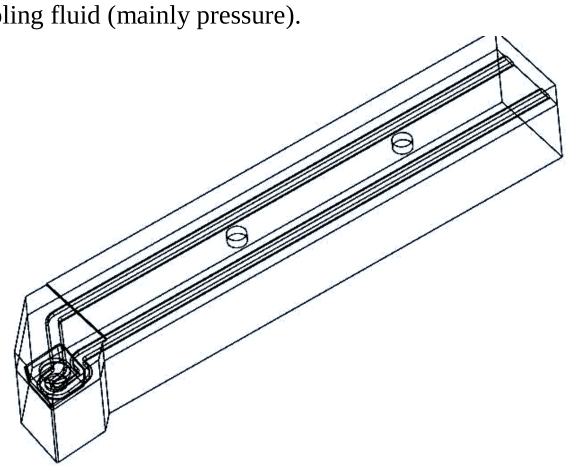

Fig. 8. Internally cooled tool with cooling channels built into the tool holder

As mentioned above, one of the main problems for internally cooled tools is the limitations imposed by technology or manufacturing capabilities. Usually internally cooled tools include relatively small fluid passages or channels, which are complicated to manufacture, especially if standard manufacturing methods are used.

One of the solutions to ease the manufacturing of the tool is to produce a holder of the cutting tool basically in two pieces (see Fig. 9). Each piece or part comprises a half of the cooling channel. When two parts are put together, they form a solid tool holder.

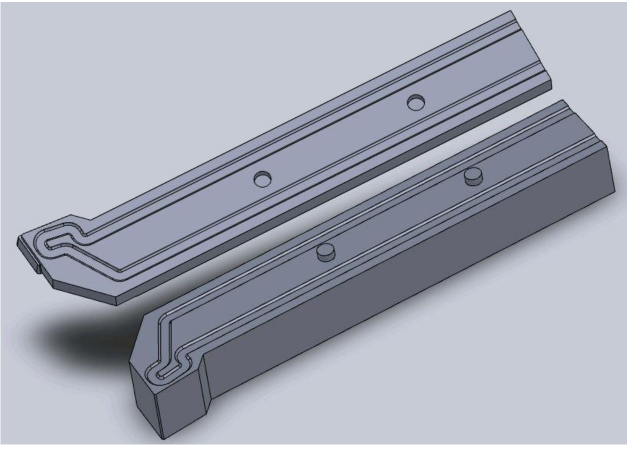

Fig. 9. Internally cooled tool in exploded view

We could also suggest that in the future one of the most promising solutions for manufacturing of internally cooled tools with any possible design is a 3D printing technology. 3D printing is new and fast growing additive manufacturing technique. This technique gives a possibility to produce a tool in any possible form and configuration. Such advantage does not restrict the design of a tool. Additionally, 3D printing can be successfully used to bring newly designed tools to the market at significantly faster pace. It means that further research should be done in close cooperation with 3D printing industry.

IV. Conclusions and Discussions

Prior art illustrates certain trends in the design of internally cooled tools. Majority of designs are still at the conceptual level. Authors do not give certain reasons why internally cooled tools are not so widely used in the industry. After extensive analysis we can conclude that a probable reason for the tools not being popular in the industry is their complicated manufacturing.

Use of 3D printing techniques can significantly improve a product life cycle - from research to application in manufacturing. 3D printing could be one of the solutions for manufacturing of tools in economically feasible manner.

The idea of using internally cooled tools is relatively new and such tools are not used in everyday life of manufacturing. We can predict that after implementation of the tighter rules on the use of cutting fluids, researches of internally cooled tools could find their way into the industry.

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His fields of scientific interest include: engineering technology, metal cutting, material science, Finite Element Method analysis and military technologies.

Artis Kromanis, Guntis Pikurs, Guntis Bunga, Kalvis Kravalis, Gatis Muižnieks, Viktors Gutakovskis. Virpošanai paredzētu iekšējās dzesēšanas instrumentu konstruēšana

Publikācijā apskatīts iekšējās dzesēšanas instrumentu zināmais tehniskais līmenis, īpaši iekšējās dzesēšanas instrumentu, kas tiek izmantoti virpošanā. Dots iekšējās dzesēšanas instrumentu dažādu konstrukciju, kā arī to attīstības tendenču apskats. Tajā laikā autori mēģina prognozēt viedo instrumentu konstrukciju turpmāko attīstību un rosina turpmākos pētījumus un diskusijas. Dota jauna iekšējās dzesēšanas instrumenta koncepcija. Šis instruments sastāv no divdaļīga instrumenta turētāja ar iekšējās dzesēšanas kanāliem un griezējplāksnītes. Turētājs ir sadalīts divas daļās, lai atvieglotu tā ražošanu. Darba laikā abas turētāja daļas ir savienotas kopā, veidojot vienu veselu griezējinstrumenta turētāju. Attiecīgi griezējinstrumenta turētājs satur dzesēšanas kanālus, kuru ieplūde un izplūde var tikt savienota ar dzesējošā šķidruma sistēmu. Attīstīto iekšējās dzesēšanas instrumentu var izmantot kā testa instrumentu turpmākajiem pētījumiem.

Артис Кроманис, Гунтис Пикурс, Гунтис Бунга, Калвис Кравалис, Гатис Муйжниекс, Виктор Гутаковский. Конструкция инструмента с внутренним охлаждением в точении.

В данной публикации рассмотрен известный уровень техники инструментов с внутренним охлаждением, особенно с внутренним охлаждением инструментов, используемых в точении. Дан обзор различных конструкций, а также тенденций в развитии инструментов с внутренним охлаждением. В то же время авторы пытаются предсказать дальнейшее развитие событий в конструкции "разумных" инструментов и предложить дальнейшие исследования и обсуждения. Дана новая концепция инструмента с внутренним охлаждением. Данный инструмент состоит из двух частей держатель инструмента с внутренними каналами охлаждения и вставной режущей пластиной. Держатель разделен на две части для удобства его изготовления. В рабочем состоянии две части держателя соединены вместе, образуя единый держатель инструмента. Соответственно держатель инструмента содержит охлаждающие каналы вход и выход которых могут быть подключены к системе охлаждения жидкости. Развитые внутренним охлаждением инструмент может быть использован в качестве испытательного стенда для дальнейших поисков.