Proceedings in Manufacturing Systems

Proceedings in Manufacturing Systems, Volume 11, Issue 1, 2016, 41–46 ISSN 2067-9238

MODERNIZATION OF COOLING UNITS FOR TOOLS AND WORKPIECES IN MACHINE TOOLS

Anca BUCUREȘTEANU[1,*], Dan PRODAN[1], Emilia BĂLAN[2], Adrian MOTOMANCEA[3]

[1)] Prof., PhD, Eng., Machines and Production Systems Department, Politehnica University, Bucharest, Romania
[2)] Assoc. Prof., PhD, Eng., Machines and Production Systems Department, Politehnica University, Bucharest, Romania
[3)] Assoc. Prof., PhD, Eng., Mechanics Department, Politehnica University, Bucharest, Romania

Abstract: *This paper presents some specific issues of the design and manufacturing of cooling units for tools and workpieces in machine tools during the cutting process. Besides the general theoretical aspects, adaptable to most of the existing machine tools, the paper lays particular emphasis on the aspects specific to modern machine tools (CNC ones), on which the machining operations are performed with high speed cutting, in the case of serial or mass production. Also this paper presents some of the simulations made in the design phase of the unit. Using these simulations one can check the behaviour of the unit before it being made, avoiding choosing unapproved parts. The unit designed and manufactured is intended for a milling machining centre with horizontal spindle, type MAXIM 11 and allows the cooling of the tool and workpiece by programmed control on the outside of the tool but, where appropriate, through the inside of the tool. The unit also allows the cooling with air or the blowing of the tool-holder taper during the automatic changing of this one from the tool-magazine. Now the unit manufactured for milling machining centre with horizontal spindle of MAXIM 11 type is functional and did not raise operating or maintenance problems for more than two years. Cooling on the outside of the tool is done with the machine working at a maximum pressure of 10 bar. Cooling onside the inside of the tool is done with the machine working at a pressure of 70–75 bar, but during commissioning it has also been tested at 90 bar.*

Key words: *machine tools, cooling unit, water emulsions, design, outside tool cooling, inside tool cooling.*

1. INTRODUCTION

Regardless of the type of tool and the workpiece material nature, heat is emitted during the cutting process on machine tools. This heat is captured by tool, workpiece and environment. A large part of it is removed at tools or workpiece level by using cooling fluids (liquids or air) [1–3]. The use of cooling has a number of advantages out of which we can mention:

- decrease of friction between the tool and the workpiece which improves the efficiency of main kinematic chain [4–6];
- the removal of the chips resulted is easily made and often directed towards the evacuation systems;
- in case of cooling one can notice an improvement of the machinability especially if the liquid has a high pressure;
- increase of tools durability;
- avoiding the modification of the characteristics of the machined material caused by heat [7].

Among the disadvantages of cooling units use, we can mention:

- complications in designing the guarding system (machine protection);
- sealing of guideways protection;
- increase of machine price by adding some specific elements [4, 8] (tank, pump, devices, pipes, etc.);
- price increase of machining operations because of the use of usually perishable liquids which belong to the consumables class.

The following elements can be used for cooling: non-emulsifiable oils, emulsifiable oils, water based solutions, special liquids, air under pressure.

The subject matter of this paper is the cooling units operating with water emulsions.

Usually, the structure of cooling units based on water emulsion use centrifugal pumps, in case of pressures up to 10–20 bar. These ones are selected from catalogues of specialized companies [9, 10]. Such a pump is shown in Fig. 1. The pumps are immersed during operation [9]. The electric motor turns the vane system by driving centrifugally the liquid sucked through the strainer 7 up to the side discharge in body 1. The elements included in the structure of these pumps are made of stainless steel, ceramic materials and rubber.

If higher pressures are wanted (70–100 bar) for tool cooling, one must use other types of pumps, such as the pumps with screws [8]. Also, these ones can operate non-immersed, providing pressures up to 120 bar. Such an electro-pump is shown in Fig. 2.

[*] Corresponding author: Splaiul Independenței 313, district 6, 060042, Bucharest, Romania
Tel.: 0040 21 402 9369;
Fax: 0040 21 402 9724
E-mail addresses: *ancab66@yahoo.com* (A. Bucureșteanu), *prodand2004@yahoo.com* (D. Prodan), *emilia.balan59@yahoo.com* (E. Bălan), *motom@deltainfo.ro* (A. Motomancea)

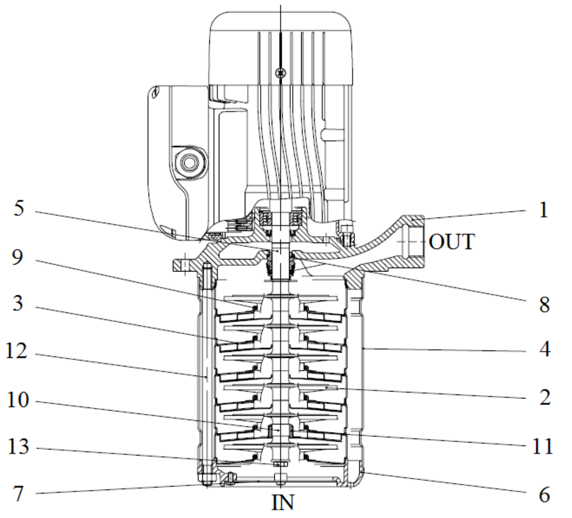

Fig. 1. Centrifugal pump: 1 – body, 2, 3 – vanes, 4 – housing, 5 – electric motor, 6 – lower cover, 7 – strainer, 8, 9 – sealing elements, 10 – spindle, 11 – sealing element, 12 – bolts, 13 – nut, *IN* – liquid inlet, *OUT* – liquid outlet.

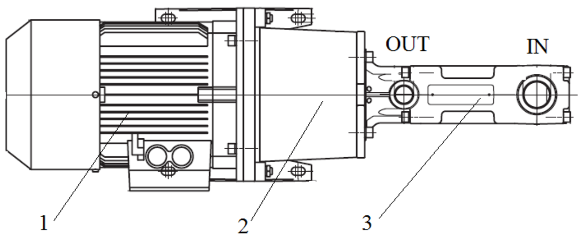

Fig. 2. Electric screw pump: 1 – electric motor, 2 – motor-pump coupling systems, 3 – screw pump, *IN* – liquid inlet, *OUT* – liquid outlet.

These pumps are made of special materials so that they can operate with water-based emulsions. They can be supplied from the tank directly or by means of low pressure pumps, like the pump in Fig. 1.

Given the working environment (water based emulsion), it is not recommended to use in the cooling units the hydraulic valves and pressure control devices intended for the hydraulic drives.

There is special equipment designed for the cooling systems in various ranges of flow and pressure, made of suitable materials [10].

In the case of inner cooling of the drilling and milling tools [4–6] it is binding to use rotary couplings. Such a coupling is shown in Fig. 3.

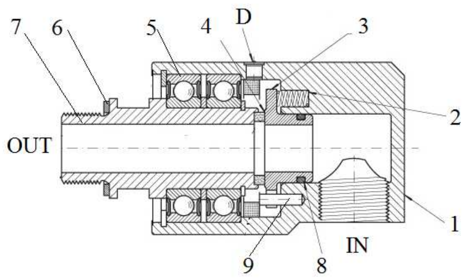

Fig. 3. Rotary couplings: 1 – body, 2 – pressing springs, 3 – movable ceramic bushing, 4 – sealing ceramic ring, 5 – bearings, 6 – sealing washer, 7 – fitting outlet, 8 – mobile sealing element, 9 – guiding elements, *IN* – supply, *D* – drain circuit, *OUT* – fitting outlet.

Element 7 is axially clamped at the end of the main spindle of the machine tool. The supply with liquid or air is made through the element 1. Its pressure and the springs 2 also press the element 3 on the ring 4 jointly with the rotating element 7. Between the ceramic surfaces of elements 3 and 4, during the rotation of the main spindle there is friction but there is also an appropriate sealing. The losses are recovered on the draining way *D*. The bearings 5 make possible the centring of the parts 1 and 7. They are provided with sealing elements. The bushing 3 is guided and protected against rotation by the elements 9. The sealing element 8 prevents the passage of the liquid between parts 1 and 3 while the washer 6 ensures the sealing of the assembly.

2. CALCULATION OF THE COOLING SYSTEMS

The calculation of these systems involves the selection of pumps and devices. In order to determine the pumps one shall consider that the entire power of the electric motor for the actuation of the main kinematic chain P_{EM}, during operation shall be transformed into heat that is taken over by the coolant. In these conditions it is possible to write, in SI:

$$P_{EM} = Q_c \cdot \rho \cdot c \cdot \Delta T \; . \qquad (1)$$

In the relation (1) it has been also noted: Q_C – cooling flow, ρ – density of liquid, *c* – specific heat of the liquid, ΔT – increase of liquid temperature.

Usually, the temperature of the liquid after cooling should be 40–45^{0}C at the most.

For the usual emulsions, the relation (1) is transformed into:

$$Q_c = 14.3 \cdot \frac{P_{EM}}{\Delta T} \; . \qquad (2)$$

In relation (2) the power P_{EM} is introduced in kW being obtained the flow Q_C in l/min.

Values in the range of 10–25 ºK are recommended for the variation of temperature ΔT, depending on the temperature of working environment.

The flow resulted from the relation above represents a minimum value.

Taking into account that only a part of the provided flow reaches exactly the tool-workpiece contact area during the cutting operation, it is recommended that the real pump to have a flow rate up to ten times higher:

$$Q_P \geq (5-10) \cdot Q_c \; . \qquad (3)$$

Another important feature of the pump is represented by the maximum working pressure. This one results from technological reasons and will be checked according to the features of equipment manufacturer.

If necessary, the power of the electric motor drive should be checked by means of the following relation, after choosing the pump:

$$P_{EMP} \geq \frac{p_{\max} \cdot Q_P}{450} \; . \qquad (4)$$

In the relation (4) it has been noted: P_{EMP} – power of pump driving electro-motor [kW], p_{max} – maximum pressure in the system [bar], Q_P – pump flow [l/min].

Nowadays, most manufacturers of such electro-pumps provide the complete characteristics: speed, flow, pressure and power; so this last calculation is no more necessary.

After choosing and selecting the pump, according to the established diagram, one shall choose the rest of the equipment on the grounds of flow rate (*DN*) and pressure like in the hydraulic units [8].

3. SIMULATION OF THE COOLING UNIT OPERATION

In order to simulate the operation [11, 12] it was considered that cooling on the outside is done with a theoretical flow of 60 l/min at a maximum pressure of 10 bar. Figure 4 presents the variation of flow and pressure in time.

The pressure developed in the circuit is 6 bar and the available flow is 58 l/min.

In the case of cooling on the outside it could be considered that flow and pressure are independent working conditions to the type of processing done. The liquid is brought through a hose into the work area.

In the case of cooling on the inside of the tool pressure and flow are dependent on the degree of the obstructing/plugging of the fluid exit area from the tool. To achieve the simulation of the operation in this case the exit of the tool was assimilated with a valve. Depending on the size of the opening one can establish the pressure and flow.

It is considered that the theoretical flow of the pump is 55 l/min and maximum pressure is 85 bar. On reaching it is considered that the tool is blocked and the cooling circuit is completely closed.

If the percentages are considered of indirect plugging in each case characteristics are obtained from Fig. 5. Obtained characteristics allow checking the operation of the unit depending on cutting conditions. Once the pressure is increased it is observed a decrease in the flow of the pumps. It should be noted that increasing pressure is favouring the removal of the chips.

4. TOOL AND WORKPIECE COOLING UNIT FOR MILLING MACHINING CENTER WITH HORIZONTAL SPINDLE

The cooling unit of the milling machining centre, type MAXIM 11 should ensure:

- tool outer cooling, low pressure (< 10 bar);
- tool inner cooling, high pressure (< 80 bar);
- air blowing inside tool;
- automatic washing of work pieces, vane and guards (in program);
- manual washing (with gun) of work pieces.

The unit must be able to operate in a totally independent manner or connected to the centralized cooling system of the workshop.

The diagram of the cooling unit of the milling machining centre with horizontal spindle of MAXIM 11 type is shown in Fig. 6.

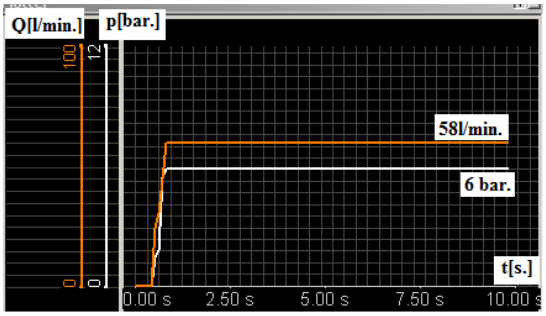

Fig. 4. Flow and pressure variation in the cooling unit on the outside of the tool

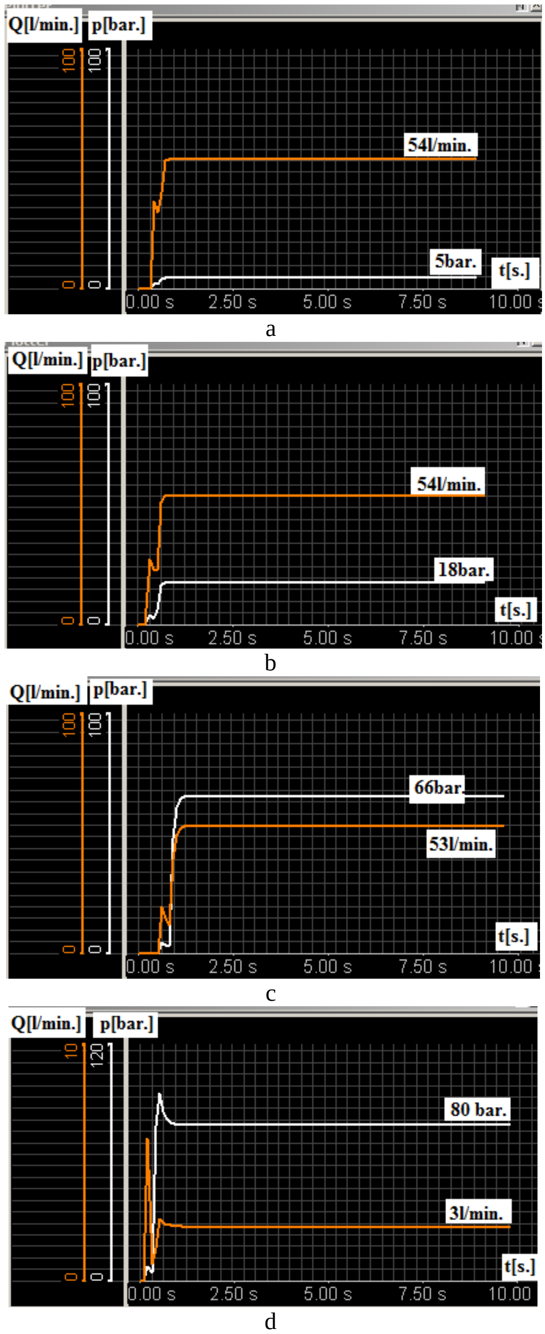

Fig. 5. Flow and pressure variation in the cooling unit on the inside of the tool: *a* – obstruction 0 %, the tool is withdrawn but the cooling unit is on, *p* = 5 bar and *Q* = 54 l/min; *b* – obstruction 50 %, the cutting process takes place with *p* = 18 bar and *Q* = 54 l/min; *c* – obstruction 75%, the cutting process takes place with p = 66 bar and Q = 53 l/min; *d* – obstruction 99 %, the cutting process takes place with p = 80 bar and Q = 3 l/min.

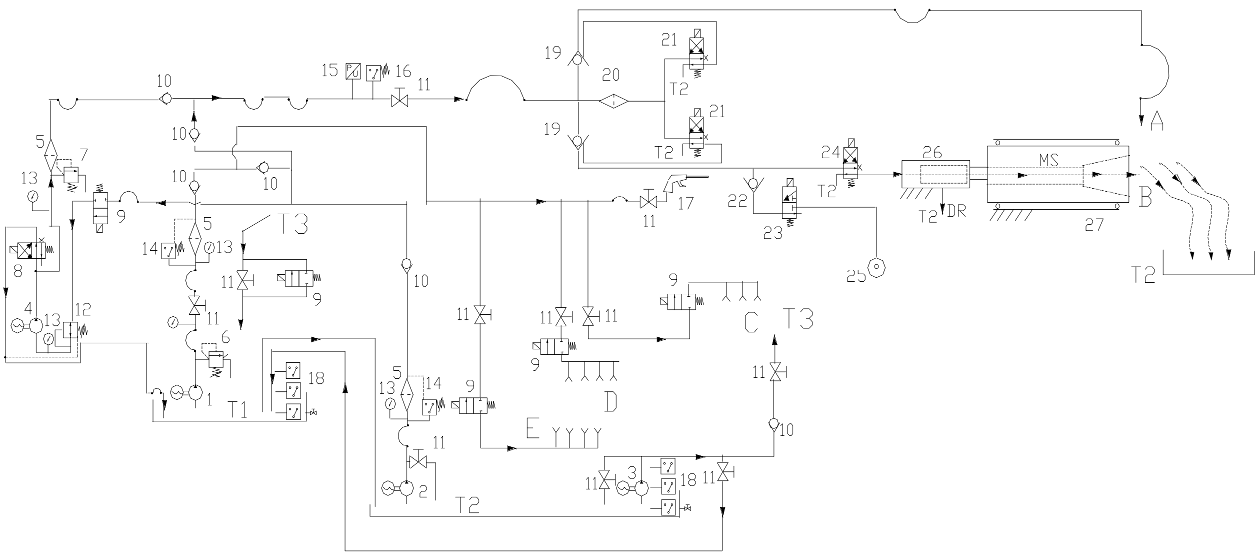

Fig. 6. Diagram of the cooling unit of the milling machining centre with horizontal spindle, type MAXIM 11.

The notations in Fig. 6 are the following ones: 1 – main pump of low pressure, 2 – secondary pump of low pressure, 3 – recirculating pump, 4 – high pressure pump (screw pump), 5 – fabric filters [13], 6, 7 – pressure limiting valve, 8 – high pressure manifolds, 9 – low pressure directional valves, 10 – check valve, 11 – manually operated valves, 12 – regulator, 13 – pressure gauge, 14 – signaling devices for filters clogging (pressure balanced relays), 15 – pressure transducer, 16 – pressure relay, 17 – manually actuated washing gun, 18 – level gauges, 19 – unlockable check valves (*DN* 25), 20 – special filter, 21 – directional valves for selecting inner or outer cooling of the tool, 22 – pneumatic check valve, 23 – pneumatic directional valve, 24 – high pressure directional valve, 25 – compressed air source (max. 10 bar), 26 – rotary coupling, 27 – machine tool main spindle (*MS*), T_1 – main tank, T_2 – secondary tank, at chips conveyor level, T_3 – centralized cooling unit, *DR* – drain circuit of the rotary coupling, *A* – tool outer cooling, *B* – tool inner cooling, *C* – workpiece washing, *D* – vane washing, *E* – guard washing.

Tool outer cooling during machining operations is normally provided at a maximum pressure of 10 bar by the pump 1. If one wants to actuate the washing of workpiece, vane or guards during machining operation, the pump 2 shall be started too in order to prevent the diminution of cooling flow rate.

For tool inner cooling it is necessary to start pump 3 too. Pump 4 is meant for liquid recirculation between tanks T_1, T_2 and the centralized cooling unit T_3. The automation of recirculation is provided by the electrical level indicators 18. Depending on the working mode, the coolant is filtered by means of filters 5 [13] and 20. These ones are equipped with clogging indicators. Pressure transducer 15 displays the real pressure in cooling circuit anytime and pressure relay 16 is so set that will confirm the maximum allowable pressure in case of failure. Valves 11 are manually actuated and allow the adjustment of the unit in different phases. Air blowing under pressure is performed by actuating the directional valves 23 and 24.

This unit makes possible the outside cooling of tools with a flow rate of ~ 60 l/min at a maximum pressure of 10 bar and the tool inner cooling at a maximum pressure of 70 bar with a flow rate of 50 l/min.

Characteristics of tool outside cooling are shown in Fig. 7 where: *p*-*Q* – characteristic of flow-pressure, η_1– pump efficiency, η_2 – electro-pump efficiency.

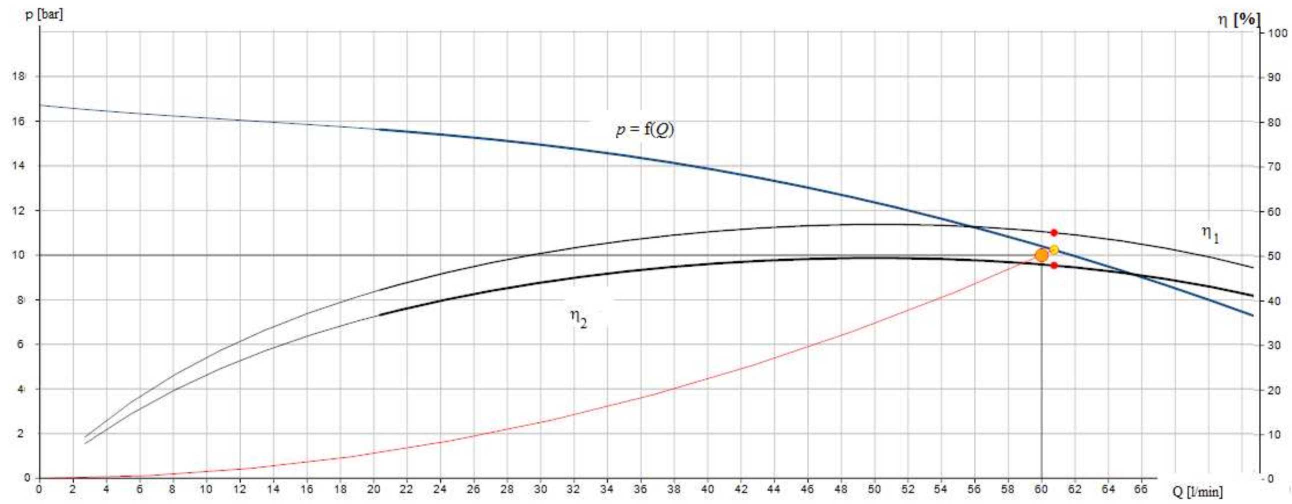

Fig. 7. Characteristics of the unit in the case of tool outside cooling.

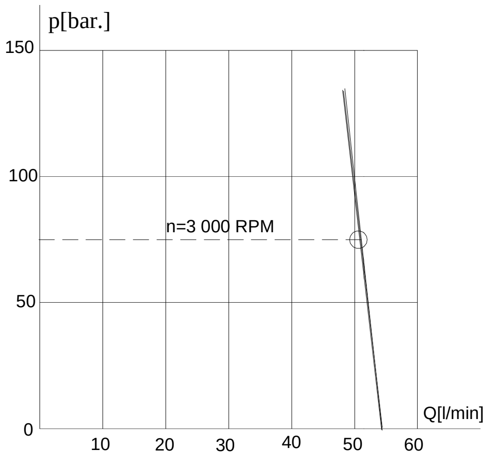

Fig. 8. Characteristics of the unit in the case of tool inner cooling.

In order to cool the tool from outside, it shall be used the characteristic flow pressure in Fig. 8, where the pump is driven at a speed of 3000 RPM.

Regardless of the mode of operation, the pressure read by means of pressure transducer 15 in Fig. 6 makes possible the very accurate determination of the cooling flow rate based on the characteristics above.

5. CONSTRUCTION OF COOLING UNIT

The cooling unit was made using various devices [10] as per diagram in Fig. 6 and characteristics of the pumps. Some parts of the real unit are shown in Fig. 9, keeping the same numbering as in Fig. 6. Assembling solutions of main and secondary pump of low pressure and recirculating pump are noticed. Also, main and secondary tanks are observed. Some details of complex construction of fabric filters, high pressure directional valves, check valves, pressure gauges are distinguished.

The cooling unit manufactured is functional and did not raise operating or maintenance problems for more than two years. Cooling onside the inside of the tool is done with the machine working at a pressure of 70–75 bar, but during commissioning it has also been tested at 90 bar.

Fig. 9. Construction details of the cooling unit: *a* – screw pump and high pressure manifolds, *b* – secondary pump & tank, *c* – fabric filters and check valves, *d* – main pump and tank, *e* – regulator and valves for pressure limitation, *f* – pressure transducer and relay.

6. CONCLUSIONS

During the remanufacture of the milling machining centre with horizontal spindle of MAXIM 11 type, its tool cooling unit was also modernized. The centrifugal pumps and the devices produced by specialized companies meet the technological requirements for pressures less than 10 bar. If high pressures are required, especially during tool inner cooling, there will be some problems out of which one can mention:

- centrifugal pumps cannot operate at pressures of 70–100 bar; in this case it is recommended to use screw pumps or reciprocating pumps;
- necessary devices (pressure relief valves and check valves, directional valves, etc.) must be selected so that they can work with the respective liquid; not all usual hydraulic equipment can operate with emulsions [14];
- it is recommended to simulate the operation of the cooling units (with specialized software) before manufacturing them [11, 12];
- it is recommended that high pressure pumps to be supplied by means of low pressure pumps;
- in the case of tool inner cooling, the coolant shall be filtered with a filtering fineness of 10 μm at least. In the case of CNC machines, the filters will be provided with clogging electrical indicators;
- it is recommended to use pressure transducers that monitor the pressure in the cooling circuit;
- for the inner cooling of milling/drilling tools rotary couplings will be used; they seal themselves only when there is a specific pressure in the circuit; at lower pressures below this one, it is possible to give losses that are drained directly to the tank;
- if the cooling unit is also used for other functions than tool cooling (workpiece washing, chip removal, etc.) during the machining operation there is a danger of diminishing the cooling flow rate; if this diminution can have negative influences, the pumps can be supplemented;
- it is recommended that diretional valves to be driven by 24 V DC electromagnets.

REFERENCES

[1] D. Prodan, R. Iacob, *Theoretical Research Regarding the Cooling Systems for Machine Tools,* Scientific Bulletin UPB, Series D: Mechanical Engineering, Vol. 66, No. 1, 2014, pp. 43–46.

[2] A. Bucureșteanu, I. Ivan, *Adjacent Installations for Machine-Tools. Modern Cooling Systems for Tool and Piece,* Journal Proceedings of the International Conference on Manufacturing Systems, Vol. 3, 2008, pp. 31–35.

[3] C. Brecher, S. Bäumler, D. Jasper, J. Triebs, *Energy Efficient Cooling Systems for Machine Tools*, Leveraging Technology for a Sustainable World, 2012, pp. 239–244.

[4] D. Prodan, *Maşini-unelte grele. Sisteme mecanice şi hidraulice.* (Heavy Duty Machine Tools. Mechanical and Hydraulically Systems), Printech Publishing House, Bucharest, 2010.

[5] P.H. Joshi, *Machine Tools Handbook*, McGraw-Hill, New Delhi, 2007.

[6] B. Perovic, *Handbuch Werkzeugmaschinen*, Carl Hanser Verlag Munchen Wien, 2006.

[7] P. Kovac, D. Rodic, V. Pucovsky, B. Savkovic, M. Gostimirovic, *Multi-output fuzzy inference system for modeling cutting temperature and tool life in face milling*, Journal of Mechanical Science and Technology, Vol. 28, Issue 10, 2014, pp. 4247 – 4256.

[8] D. Prodan, M. Duca, A. Bucureșteanu, T. Dobrescu, *Acţionări hidrostatice. Organologie* (Hydrostatic Drives. Study of Parts), AGIR Publishing House, Bucharest, 2005.

[9] A. Bucureșteanu, *Instalaţii conexe pentru maşini-unelte şi sisteme de producţie* (Auxiliary Units for Machine Tools and Production Systems), Printech Publishing House, Bucharest, 2009.

[10] * * * Catalogues of DANFOSS, LOWARA, GRUNDFOS, HYDAC, BRINKMANN, GUSHER (http://www.danfoss.ro,http://www.lowara.com, http://www.grundfos.com,http://www.hydac.ro, http://www.brinkmannpumps.com,http://www.gusher.com)

[11] http://www.automationstudio.com (Hydraulic and Pneumatic Simulation Software)

[12] D. Prodan, *Maşini-unelte. Modelarea şi simularea elementelor şi sistemelor hidrostatice* (Machine Tools. Modeling and Simulation of Hydrostatic Systems and Elements), Printech Publishing House, Bucharest, 2006.

[13] D. Prodan, A. Bucureșteanu, D. Bucur, *The Sustainable Development - A Form of Economic Improvement. Part II. Design and Simulation of Stands Meant for Testing the Textile Filter Element*, in Journal ”Industria Textilă”, No. 5, 2009, pp. 279–283.

[14] D. Prodan, A. Bucuresteanu, E. Bălan, *Research on the Possibility of Replacing Oil with Water in Hydrostatics Units of Machine Tools*, Applied Mechanics and Materials, Vol. 656, 2014, pp. 121–128, Trans Tech Publications, Switzerland, DOI:10.4028/www.scientific.net/AMM.656.121.