



OPTIMAL DESIGN OF COOLING SYSTEM FOR THE PLASTIC INJECTION MOLDS

Simion HARAGĂȘ, Cristina TUDOSE

Abstract: In this paper is presented an optimal design method with evolutionary algorithms cooling system from a mold. Watch a channel to maximize cooling surfaces to reduce cooling time, which implicitly leads to increased productivity.

Key words: optimal design, evolutionary algorithms, cooling system, pneumatic ejector.

1. INTRODUCTION

For a piece injected thin-walled truncated cone shape (Fig. 1) we know: its size and weight and the material used is polypropylene. We know also the dimension of injection mold.

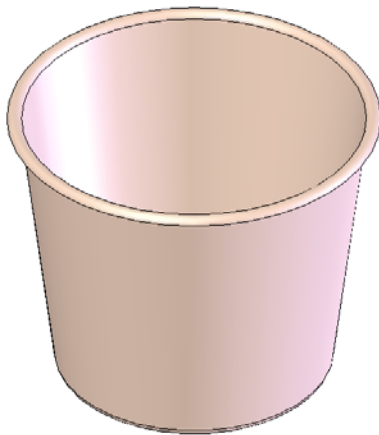


Fig. 1 Injected part

The ejector system of injected piece contains an air valve and a double action pneumatic ejector (Fig.2).

We follow an optimal redesign of core cooling system in conjunction with the system so as to obtain a surface to maximize the cooling channels. By maximizing the cooling channels surface during cooling and thus reduce the total cycle time of injection. Meanwhile the pneumatic ejector should be designed so that at the ejection from mold, the injected piece speed to establish a adequate

trajectory. If speed is too low then the piece is not shed from the core, and if speed is too high will hit the track injected fixed part of mold (with the risk of damage to the part injected).

After opening the mold by air entering pneumatic valve separation performed on the core piece injected. The song remains the core at a distance from the front surface x_{impact} it. Pneumatic pitcher throws strikes and a piece of the core. There is a clash about elastic between pneumatic and track injected stem shooter. Knowing the shooter when the impact speed, mass and mass of the moving part of the shooter can calculate the speed v_0 at throwing the piece of mold injected:

$$v_0 = c_{dam} \cdot \frac{2 \cdot v_{ai}}{\left(1 + \frac{m_p}{m_a}\right)} \quad (1)$$

where:

v_{ai} – pneumatic ejector mobile elements velocity before impact, [m/s];

m_p – injected part weight, [kg];

m_a – pneumatic ejector mobile elements weight, [kg];

c_{dam} – damping coefficient; it takes into consideration that the part velocity after impact will be lower due to the energy dissipation at impact because of injected part material elasticity ($c_{dam} = 0.8$ experimentally determined).

The velocity v_{ai} is determined by solving the motion equation of pneumatic ejector piston and the differential equations of air pressure in

working chambers of pneumatic ejector system (issues presented in the paper [4]).

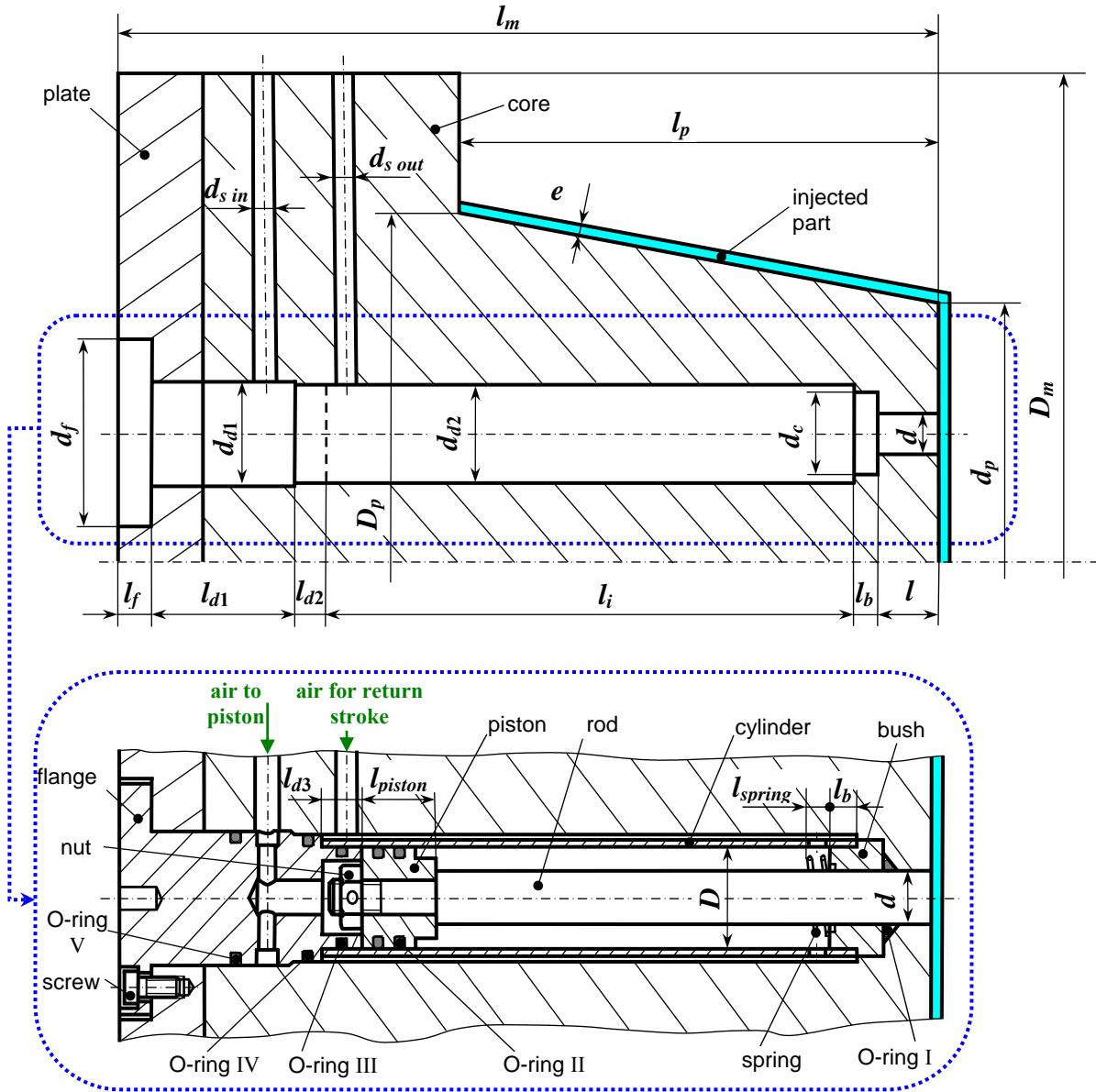


Fig. 2 Pneumatic ejector and its position in the mold

2. COOLING SYSTEM DIMENSIONING

Core cooling system consists of several cooling channels whit baffle. Figure 3 shows a section of an axial cooling channel, and Figure 4 a sketch of the location of these channels. Sealing cooling channels is done using O rings

Part calorific ceded injected mold during the injection cycle is [1]:

$$P_Q = \frac{3600}{t_c} \cdot m_p \cdot (i_2 - i_1) \text{ [kJ/h]} \quad (2)$$

where:

t_c – total time of an injection cycle, [s];

m_p – injected part weight, [kg];

i_2, i_1 – enthalpy corresponding entry temperatures in plastic mold, mold release, respectively, [kJ/kg].

Neglecting convection and radiation losses, heat is drained through the cooling circuit.

$$P_Q = k_T \cdot S \cdot \Delta T \quad [kJ/h] \quad (3)$$

where:

k_T – global heat exchange coefficient, [kJ/m²·h·°C];

S – surface area of the internal cooling channels, [m²];

ΔT – temperature difference between the nest and cooling circuit, [°C]. Global heat exchange coefficient is calculated by the relationship [6]:

$$\frac{1}{k_T} = \frac{1}{\alpha_T} + \frac{\delta}{\lambda} \quad (4)$$

where:

δ – distance between cooling channel and nest, [m];

α_T – coefficient of heat transmission fluid cooling, [kJ/m²·h·°C];

λ – thermal conductivity coefficient of the matrix material is performed, [kJ/m·h·°C]. The coefficient of heat transmission fluid α_T is calculated with the formula [6]:

$$\alpha_T = 19,37 + 0,27 \cdot T_1 \cdot \Delta_m^{0,9} \quad (5)$$

where:

T_1 – inlet temperature in the cooling circuit, [°C];

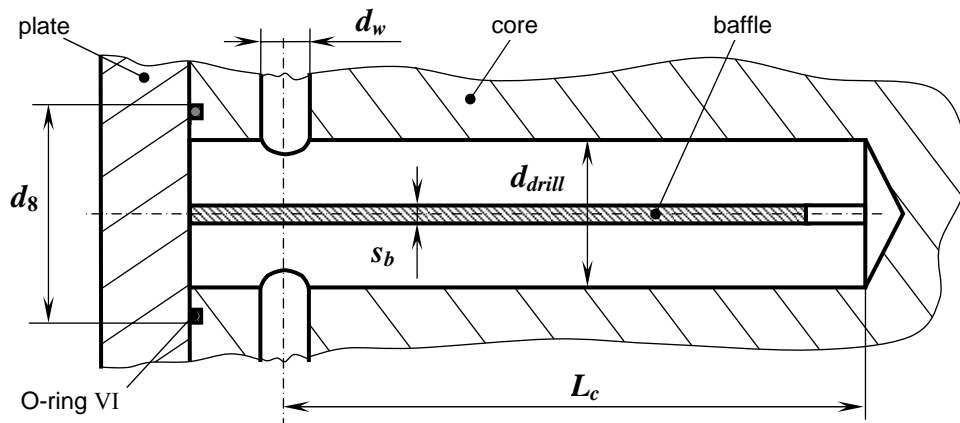


Fig. 3 Cooling channel whit baffle

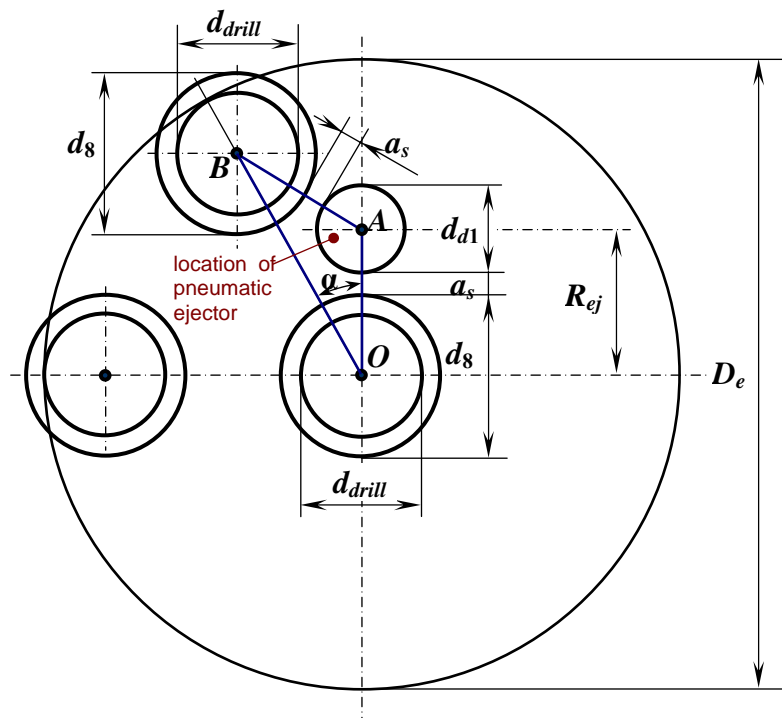


Fig. 4 Location of cooling channels

Δ_m – mass flow of the cooling circuit, [kg/m²·h], is calculated by the relationship [6]:

$$\Delta_m = v_f \cdot \rho_r \cdot 10^{-4} \quad (6)$$

where: v_f – velocity of fluid, [m/h], ($v_f = 3600 \cdot 0,6$ m/h, for water);

ρ_r – coolant density, [kg/m³].

From relations (2) and (3) results:

$$t_c = \frac{3600 \cdot m_p \cdot (i_2 - i_1)}{k_T \cdot \Delta T} \cdot \frac{1}{S} \quad [s] \quad (7)$$

From equation (7) that the cooling time is inversely proportional to the surface of the cooling channels. Thus, with increasing cooling channel surface, while cooling will decrease (assuming all other quantities remain constant).

For cooling channels with baffle (Fig. 3) cooling surface is calculated with the relation [5]:

$$S = (\pi \cdot d_{drill} - 2 \cdot s_b) \cdot L_c \quad (8)$$

where:

d_{drill} – cooling channel diameter, [m];

s_b – baffle width, [m];

L_c – length (height) channel cooling, [m].

The original version was the cooling system consists of 4 cooling channels with baffle (Φ 0.036 m) and a cooling channel with baffle (Φ 0.04 m). The surface cooling was in this case, $S_{cooling\ initially} = 1.549 \cdot 10^{-5}$ m².

3. OPTIMAL DESIGN OF THE COOLING SYSTEM

3.1 Objective function

Target area was established as a function of the inner surface of core mold cooling channels, aiming to be a maximization of it. The size and location of cooling channels will be affected directly by the size and location of pneumatic shooter.

Objective function will therefore be:

$$S_{cooling} = n_{cb} \cdot (\pi \cdot d_{drill} - 2 \cdot s_b) \cdot L_c \rightarrow \max \quad (9)$$

where:

n_{cb} - the number of cooling channels with baffle.

3.2 Optimization program

For optimal design using evolutionary algorithms optimization program *Cambrian v. 3.2*. In Table 1 the input data.

In Table 2 are genes chosen to solve the problem of optimal design. Each list contained four rings of rings with diameters of 1.8, 2.65, 3.55 and 5.3 mm.

3.3 Constraints

The following thirteen constraints were identified and used in the optimization program:

R1 Between d and D must be a minimum of radial space (t_{ret}) that are double-action ejector. At the end of the race throwing compressed air gets between rod and cylinder causing the shooter back to the starting position:

$$\frac{D - d}{2} \geq t_{ret} \quad (10)$$

R2 Between D_{d1} and d_{d2} must be a minimum radial difference ($t_{mounting}$) allowing installation without damaging the ring IV:

$$\frac{d_{d1} - d_{d2}}{2} \geq t_{mounting} \quad (11)$$

R3 Bore diameter D must be smaller than the outside diameter d_c :

$$D < d_c \quad (12)$$

R4 Difference between d_c and D can not be more than twice the pipe walls h_c :

$$d_c - D \leq 2 \cdot h_c \quad (13)$$

R5 Pipe wall thickness can not be less than a minimum value set:

$$g_6 = \begin{cases} d_c - D \geq 2 & \text{if } d_c \leq 25 \\ d_c - D \geq 3 & \text{if } d_c > 25 \end{cases} \quad (14)$$

R6, R7 The ratio d/d_p has to lie in a certain range:

$$0,07 \leq \frac{d}{d_p} \leq 0,2 \quad (15)$$

Table 1

Data entry program for optimal cooling system design

Parameter	Denotation	Value
Outer diameter of the core	D_p	0.270 m
Inner diameter of the core	d_p	0.206 m
Thickness of the core	l_p	0.235 m
Injected part weight	m_p	0.321 kg
Length of the injected mold	l_m	0.33 m
Air admission hole diameter	$d_{s in}$	0.006 m
Air evacuation hole diameter	$d_{s out}$	0.006 m
Total length of hole of diameter $d_{s in}$	$l_{s in1}$	0.025 m
Circular admission channel width	l_{dd1}	0.008 m
Piston stroke	x_{impact}	0.007 m
Part initial minimum speed in order detach the part from the core	v_{0min}	1.646 m/s ²
Part initial maximum speed in order to avoid the collision	v_{0max}	2.857 m/s ²
Baffles width	s_s	0.0025 m
Depth (length) of the cooling channel	L_c	0.28 m
Maximum diameter of the circle tangent to the cooling channels	$D_{e max}$	0.19 m
Maxim circle radius on which is fitted the pneumatic ejector	$R_{ej max}$	0.06 m
Minimum distance between the ring channels VI	a_s	0.004 m
Water input hole diameters	d_w	0.01 m
Allowable crushing stress of the injection part material at the demolding temperature	σ_{as}	10 MPa

Table 2

Genes design problem of optimal cooling system

Gene	Part	No. of values in list	Parameter
0	Pipe (cylinder)	64	d_c - outer diameter of the stainless steel pipe h_c - thickness of the stainless steel pipe
1	O-ring I	64	d - rod diameter $d_{O ring 1}$ - diameter of the O-ring I
2	O-ring II	64	D - inner diameter of the cylinder $d_{O ring 2}$ - diameter of the O-ring II
3	O-ring V	64	d_{d1} - plug shoulder diameter $d_{O ring 5}$ - diameter of the O-ring V
4	O-ring VI	32	d_8 - outer diameter of the channel O-ring VI d_{drill} - diameter of the cooling channel
5	Number of cooling channels	2	n_{cb} - number of cooling channels (5 or 7)

R8 Ejector must not damage the bottom wall of injected part:

$$\sigma_b = \frac{4 \cdot F_a}{\pi \cdot d^2} \leq \sigma_{ab} \quad (16)$$

where:

σ_b – bearing pressure;

F_a – extraction force;

$$F_a = m_a \cdot a_{ai} \quad (17)$$

a_{ai} – acceleration of mobile elements ejector before impact, [m/s].

R9 Initial speed of the piece injected (after impact) must be greater than the minimum speed (to avoid remaining on the core):

$$v_0 \geq v_{0\min} \quad (18)$$

R10 initial speed of the piece injected (after impact) should be less than the maximum speed (to avoid collisions with fixed semi-mold)

$$v_0 \leq v_{0\max} \quad (19)$$

R11 Diameter circle tangential to the cooling channels (Fig. 6) can not be greater than a maximum:

$$D_e = 2 \cdot (d_8 + 2 \cdot a_s + d_{d1}) \cdot \cos \alpha + d_{drill} \leq D_{e\max} \quad (20)$$

R12 Radius of the circle that is mounted ejector (Fig. 6) must be less than a maximum:

$$R_{ej} = \frac{1}{2} \cdot (d_8 + 2 \cdot a_s + d_{d1}) \leq R_{ej\max} \quad (21)$$

R13 Where $n_{cb} = 7$ between water holes and cooling channels must be a safe distance as:

$$\frac{D_e - 2 \cdot d_g - 3 \cdot d_{drill}}{4} \geq a_s \quad (22)$$

3.4 Optimization results

The results are presented in Table 3.

All six variants are convenient. Was chosen the first variant, in which case stainless steel pipe does not require further processing.

The numerical values of all relevant dimensions of cooling system components and corresponding pneumatic ejector variant chosen (marked with different background in Table 3) are given in Table 4.

Cooling surface increased from the original version of the original $S_{cooling\ initially} = 1.549 \cdot 10^{-5} \text{ m}^2$ a $S_{cooling\ opt} = 2.026 \cdot 10^{-5} \text{ m}^2$, an increase of 30.8%. Considering that all other sizes remain constant injection process will result in a reduction in cooling time and hence the total cycle time of injection. Direct consequence of this will increase productivity.

In Figure 5 is presented the initial version of cooling system of semi-mold and in Figure 6 the cooling system optimized version.

Table 3

The results of the cooling system optimization

Position in list for Pipe	Position in list for O-ring I	Position in list for O-ring II	Position in list for O-ring V	Position in list for O-ring VI	Number of cooling channels	Surface cooling channels $S_{racire}, [\text{m}^2]$
17	9	21	15	13	7	$2.0263 \cdot 10^{-5}$
18	9	21	15	13	7	$2.0263 \cdot 10^{-5}$
19	9	21	15	13	7	$2.0263 \cdot 10^{-5}$
19	9	21	28	13	7	$2.0263 \cdot 10^{-5}$
18	9	21	28	13	7	$2.0263 \cdot 10^{-5}$
17	9	21	28	13	7	$2.0263 \cdot 10^{-5}$

Table 4

Optimal cooling system components

Pipe (REV INOX)		O-ring I (ISO 3601)		O-ring II (ISO 3601)		O-ring V (ISO 3601)		O-ring IV (ISO 3601)		Cooling channels	
d_c [mm]	h_c [mm]	d [mm]	$d_{Oring\ 1}$ [mm]	D [mm]	$d_{Oring\ 2}$ [mm]	d_{d1} [mm]	$d_{Oring\ 5}$ [mm]	d_7 [mm]	$d_{Oring\ 6}$ [mm]	d_{drill} [mm]	Number of channels
30	1.5	15	2.65	27	3.55	35	2.65	38.7	2.65	34.5	7
		Symbol		Symbol		Symbol		Symbol			
		26501500		35502000		26502240		26503870			
v_{ai} [m/s]		a_{ai} [m/s ²]		v_0 [m/s]		Surface cooling channels $S_{cooling}, [\text{m}^2]$					
2.3892		402.596		2.2304		$2.0263 \cdot 10^{-5}$					

4. CONCLUSIONS

- Optimal design of refrigeration systems in injection molds is done depending on the

type of cooling system in conjunction with the throw.

- Cooling system optimal design was done taking into account the possibility of carrying it in terms of technology.

- The optimal cooling system design has achieved an increase of 30.8% of mobile part of the mold surface cooling which leads to increased productivity.

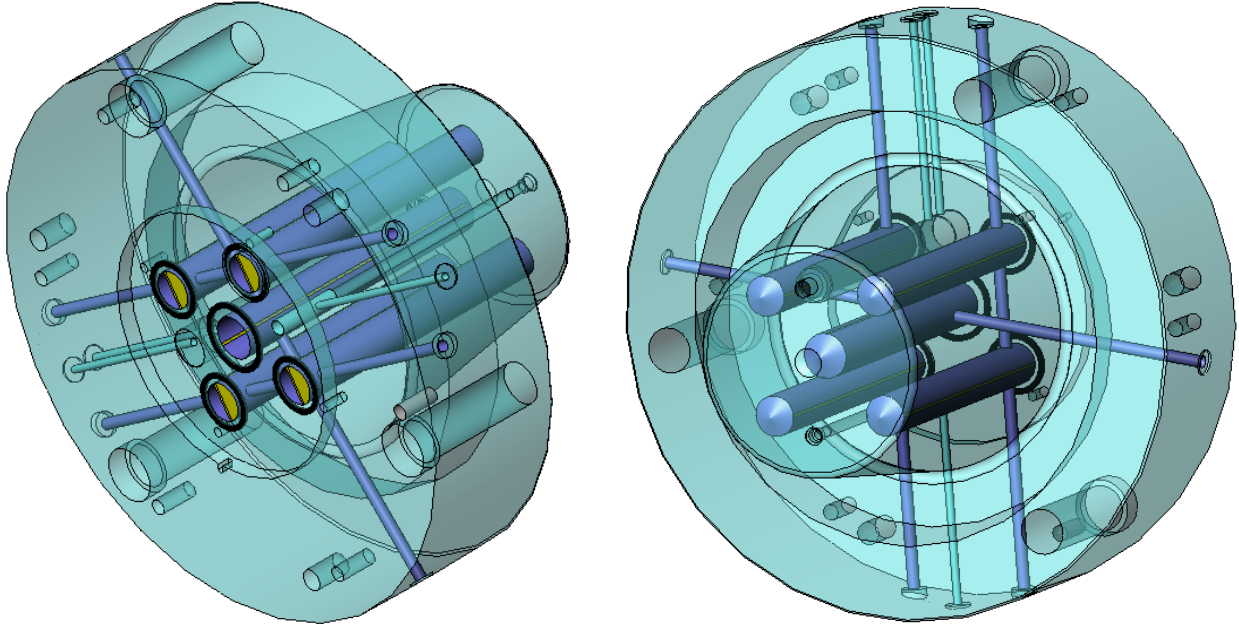


Fig. 5 The movable mold cooling system (initial version)

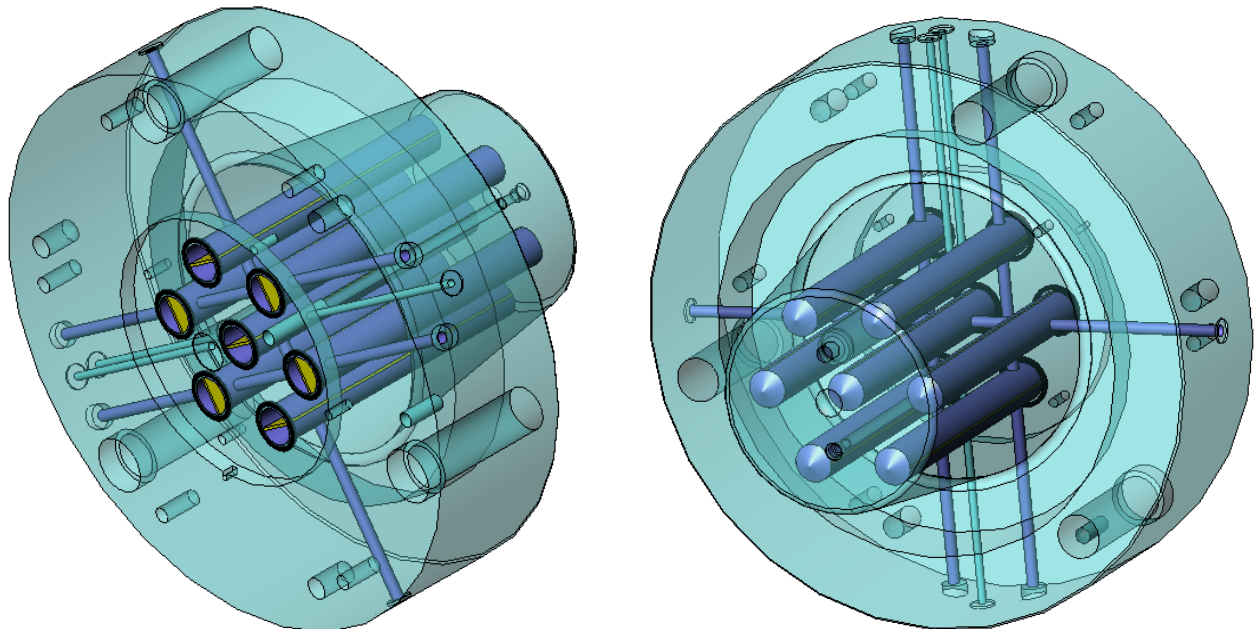


Fig. 7 The movable mold cooling system (after optimization)

5. ACKNOWLEDGEMENTS

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PROIECTAREA OPTIMALA A SISTEMULUI DE RACIRE LA MATRITILE DE INJECTAT

Lucrarea prezintă o metodă de proiectare optimală cu algoritmi evolutivi a sistemului de răcire de la o matriță de injectat. S-a urmărit o maximizare a suprafețelor canalelor de răcire pentru reducerea timpului de răcire, ceea ce duce implicit la creșterea productivității.

Simion HARAGÂȘ, PhD, Associate Professor, Technical University of Cluj-Napoca, Department of Mechanical Engineering Systems, Simion.Haragas@omt.utcluj.ro, +40264401665.

Cristina TUDOSE, PhD, Assist. Professor, Technical University of Cluj-Napoca, Department of Mechanical Engineering Systems, Cristina.Stanescu@omt.utcluj.ro, +40264401665.