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COOLING / HEATING SYSTEM OF THE INJECTION MOLDS

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ABSTRACT

The plastic injection molds have special requirements for the cooling / heating system. The designers have to accept and keep the rules for the design of the cooling channels in the molds. In current paper basic rules in the heating/cooling design as well as heat flows balance have been elaborated. Focus has been placed on channel diameter and heat distribution. The contribution shows the analytic way and finite elements method as an exact and practical tools in mold design.

Key words: *Injection molding, Design, Cooling System*

1. INTRODUCTION

One of the step in the plastic injection mould design is the calculation and than the design of the cooling / heating system. The plastic mass which is injected to the mould has to be cooled down under the melt temperature to the de-moulding temperature. The first thing which enters to the design is the own design of the part and the choice of its material. The cooling / heating system should be designed as one of the first thing, not as a last step after the tool design is finished. The cooling / heating system design has to follow the procedure which will be shown in this contribution. In the beginning we will shortly introduce the basic function of the mould cooling system and sum up the basic rules in the design.

2. BASIC RULES IN THE COOLING / HEATING DESIGN

The injection moulding process starts with the injection of the melted plastic material to the mold. After this step the machine switches to the holding pressure and presses the melted plastic to the mould till the gate gets frozen. After this the machine is preparing next shot and the tool stays closed for approximately double time of the holding pressure. During this time the plastic is cooled by the heat transfer with the cavity wall of the mould. The tool has to be tempered with cooling / heating medium all the time to ensure the right temperature of the cavity wall. This temperature is recommended by the material suppliers and has to ensure correct structure of final part and also efficient cooling during the production. The cooling / heating medium is usually water, sometimes oil when the temperature of tool has to be higher than 90 °C. The cooling channels use to be cylindrical or rectangle. The cooled parts of the mould are generally: the frame, cavity inserts and the cores if necessary. The basic task of the system is to cool the part uniformly without high temperature differences over the part surface. This problem could lead to the stress in the cold part and to creation of the deformations or depressions. The temperature difference on the cavity wall should be between 5 - 10 % for the amorphous thermoplastics and between 2.5 – 5 % for semi-crystalline thermoplastics. Due to this rule the constructer has to design better more channels close to each other with smaller diameter and also consider carefully the position of the channels to cover all part geometry. For the design and than a verification of the heating / cooling system we can use the analytical way or the finite elements method. The best is to use both together with the experience and intuition. The first input to the analytical calculation is the heat flow equation.

3. HEAT FLOWS

During the injection moulding process the following heat flows enters to the system of mould, cooling circuit and machine. Together all heat flows are in balance.

$$\dot{Q}_P + \dot{Q}_W + \dot{Q}_{CV} + \dot{Q}_{CD} + \dot{Q}_R + \dot{Q}_H = 0$$

$\dot{Q}_P$ - the heat flow of melted plastic material injected to the mould

$\dot{Q}_W$ - the heat flow which the cooling / heating medium (water) is transporting out

$\dot{Q}_{CV}$ - the heat flow based on the convection with the air

$\dot{Q}_{CD}$ - the heat flow based on the conduction to the machine plates

$\dot{Q}_R$ - the heat flow based on radiation

$\dot{Q}_H$ - the heat flow of the hot runners if they are used

Figure 1 shows the heat flows balance. The red highlighted arrows means the heat flows which are going out from the system and green highlighted arrows represents the heat flow which goes into the system. The radiation, convection and conduction heat flows together are indexed as “s”, what means surrounding.

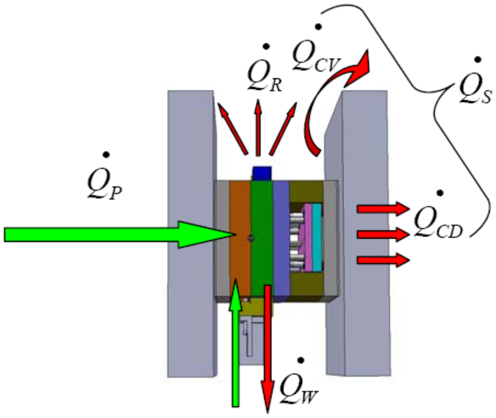

Fig.1 - Heat flows in the plastic injection process

When all the inputs are known, there is needed to calculate all the heat flows above. The heat flow of the plastic is determinate by the enthalpy difference of the cooled polymer.

$$\dot{Q}_P = \frac{m \cdot (h_1 - h_2)}{t_C}$$

where „m“ is the total shot weight and t_C is the cycle time.
The cycle time is very difficult to determine, generally it is a quadrate function of the wall thickness of the part. The heat flow of the convection is calculated with the coefficient of heat transfer of the air, the free area of the mould and the temperature difference between the mould temperature and the air.

$$\dot{Q}_{CV} = A_F \cdot \alpha_{AIR} \cdot (\vartheta_M - \vartheta_{AIR})$$

Conduction heat flow is calculated with the area of the tool which is in touch with the machine plates, heat transfer coefficient of the mould (tool and the insulating plates) and the temperature difference between the mould and the surrounding.

$$\dot{Q}_{CD} = A_T \cdot \beta_M \cdot (\vartheta_M - \vartheta_S)$$

The radiation heat flow is determinate with usage of the radiation coefficient, radiation coefficient of black body and temperatures of the mould and surrounding.

$$\dot{Q}_R = \varepsilon \cdot C_S \cdot \left[\left(\frac{T_M}{100} \right)^4 - \left(\frac{T_S}{100} \right)^4 \right]$$

Now we have the last item of the balance equation. The last item is the heat flow from the cooling / heating medium. The equations below will lead to determination of the throughput of the water in the channel. The maximal output – input temperature distance should be lower than 2 °C.

$$\dot{Q}_W = \dot{Q}_F + \dot{Q}_H - \dot{Q}_{CV} - \dot{Q}_{CD} - \dot{Q}_R$$

$$\dot{m}_W = \frac{\dot{Q}_W}{c_W \cdot (\vartheta_{IN} - \vartheta_{OUT})}$$

where c_W is the specific heat capacity of water.

4. CHANNEL DIAMETER

The diameter of the cooling channels has direct influence to the heat amount which will be taken out after the hot plastic melt would be injected. The efficiency of the cooling depends on the heat transfer coefficient and this coefficient is rising extremely when the Reynolds number is bigger than 2 300. To achieve good value of Reynolds number (turbulent flow) is needed sufficient velocity of water in the channels. The velocity and Reynolds number go up with decreasing diameter of the channel. The result of this fact advises that better is to make thinner channels and to increase the cooling efficiency to make them longer with higher density through the mould.

$$\mathrm{Re} = \frac{v_W \cdot D_{CH}}{\nu}$$

where v_W means the velocity of water, D_{CH} is channel diameter and ν means kinematic toughness of water.

5. TEMPERATURE DISTRIBUTION

The temperature distribution is shown in figure 2. The temperature of the heating cooling medium is here known and from this temperature is possible to calculate the temperature of the channel wall and than the temperature of the cavity wall.

$$\vartheta_{CH} = \vartheta_W + \frac{\dot{Q}_F - \dot{Q}_S}{2 \cdot A_{CH} \cdot \alpha_W}$$

temperature of the cooling / heating channel

$$\vartheta_{CW} = \vartheta_{CH} + \frac{\dot{Q}_P \cdot \delta \cdot n}{2 \cdot A_P \cdot \lambda_M}$$

temperature of the cavity wall (function of the channel temp., plastic heat flow, cavity number, cavity surface and thermal conductivity of the mould)

Now the temperatures are described. As the last step of the calculations the temperature differences on the cooled cavity wall have to be determinate. The temperature of the wall depends on the channel geometry. The figure 3 describes the behavior of the temperature between two channels as a function of the dimensions B and C.

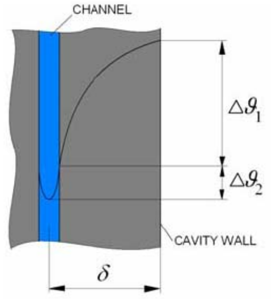

Fig.2 - Temperature distribution through the mould wall

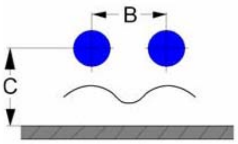

Fig.3 - Influence of the channels geometry to the temperature of the cavity wall

The difference in the cavity wall can be counted as the function of Biot number and the B, C dimensions.

$$j = 2{,}4 \cdot Bi^{0,22} \cdot \left(\frac{B}{C}\right)^{2,8 \cdot \left|\ln\left(\frac{B}{C}\right)\right|} [\%]$$

The temperature difference should be as low as possible to insuring of the homogenous field of temperature. The pressure loses are counted from basic equations from hydrodynamic, where the factor ξ as a friction coefficient is used. The losses are formed with the channel roughness, the bends in the circuit, the sharp edges etc. The signification of the pressure losses knowledge is in the correct proposal of the pump capacity to ensure required throughput of water.

6. APPLICATION

As the application of the analytical calculation we use the project “Screwdriver”. The Screwdriver is the new designed mould which will be used for the scientific proposals. The influence of the metal insert temperature to the plastic structure will be explored. The screwdriver part is made of 3 components – metal part, PA 6 - Orbimid B 27 body and the soft handle from TPV – Santoprene 8291 – 85PA. For this part which is shown on the figure 4. we calculated all the values described in theoretical introduction of this contribution. The results are shown in the table 1.

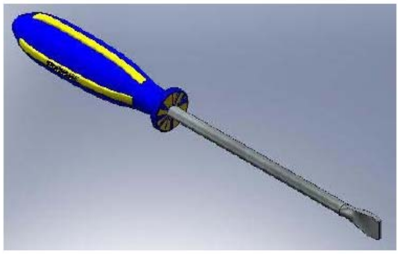

Fig.4 – Part screwdriver

Table 1. Results of the analytical calculation for screwdriver PA6 component

COOLING / HEATING SYSTEM DESIGN					
PART NAME:	**SCREWDRIVER**				
MATERIAL:	**PA6 - ORBIMID B27**				
FILL DOWN			**RESULTS**		
MELT TEMPERATURE	255	°C	**HEAT FLOWS**		
WATER TEMPERATURE	73	°C	CYCLE TIME CALCULATED (ONLY FOR INFORMATION)	160	s
PLASTIC ENTALPHY DIFFERENCE	600	kJ / kg	PLASTIC HEAT FLOW	0,53	kW
TOTAL SHOT WEIGHT	40	g	CONVECTION HEAT FLOW	0,08	kW
MAXIMAL WALL THICKNESS	8	mm	CONDUCTION HEAT FLOW	0,15	kW
TOOL SIZE - a	246	mm	RADIATION HEAT FLOW	0,02	kW
TOOL SIZE - b	190	mm	WATER HEAT FLOW	0,28	kW
TOOL SIZE - c	205	mm	**WATER THROUGH-PUT**		
CAVITY NUMBER	1	-	WATER THROUGHPUT THEORETICAL (ONLY FOR INFORMATION)	4,02	l / min
RING DIAMETER	125	mm	IN / OUT WATER TEMPERATURE DIFFERENCE	1,00	°C
ESTIMATED CYCLE TIME	45	s	VELOCITY OF WATER	2,36	m / s
INSULATION PLATES THICKNESS	2	mm	REYNOLDS NUMBER	34271,87	-
RADIATION COEFFICIENT	0,25	-	**TEMPERATURES**		
HOT RUNNER HEAT FLOW	0	kW	PRANDTL NUMBER – Pr	2,47	-
CHANEL DIAMETER	6	mm	NUSSELT NUMBER - Nu	131,64	-
KINEMATIC TOUGHNESS OF WATER	4,13E-07	m^2 / s	COEFFICIENT OF HEAT TRANSFER OF WATTER	15358,40	W / (m^2 K)
TOTAL CHANNEL LENGTH	0,70012	m	CHANNEL WALL TEMPERATURE	74,32	°C
THERMAL CONDUCTIVITY OF WATER – LAMBDA	0,7	W / (m K)	CAVITY WALL TEMPERATURE	79,61	°C
THERMAL CONDUCTIVITY OF WATER - a	1,675E-07	m^2 / s	BIOT NUMBER - Bi	131,64	
PART SURFACE	14729	mm^2	DIFFERENCE OF THE CAVITY WALL TEMPERATURE - J (%)	15,68	%
DISTANCE BETWEEN THE CHANNELS - B	40	mm	DIFFERENCE OF THE CAVITY WALL TEMPERATURE - J (°C)	12,49	°C
DISTANCE OF CHANNEL FROM THE PART – C	23,41	mm	**PRESSURE LOSSES**		
NUMBER OF BENDS IN CHANNELS	2	-	TOTAL PRESSURE LOSSES IN THE CHANNELS	68,76	kPa
NUMBER OF SHARP (90°) EDGES IN CHANNELS	14	-	PUMP CAPACITY	0,28	kW
WATER THROUGHPUT CHOSEN	4	l / min			

7. MOLD FLOW ANALYSIS

As the second step of the cooling / heating system was the mold – flow analysis created. The procedure of the mold – flow analysis includes the creating of the part model together with the gating and cooling circuit. Then the mesh has to be created. For our proposal we have used the 3D mesh because the part is thick – walled. After the meshing it is needed to assign the material properties, the process parameters and the analyze character. The selection from the mold – flow analysis results is shown on the Fig. 5, 6, 7.

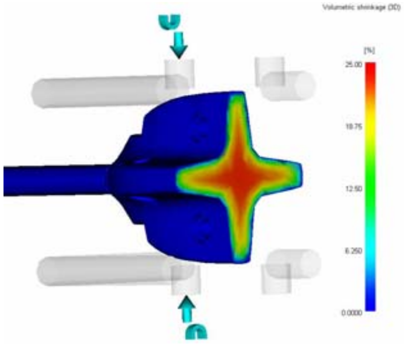

Fig.5 - Volumetric shrinkage

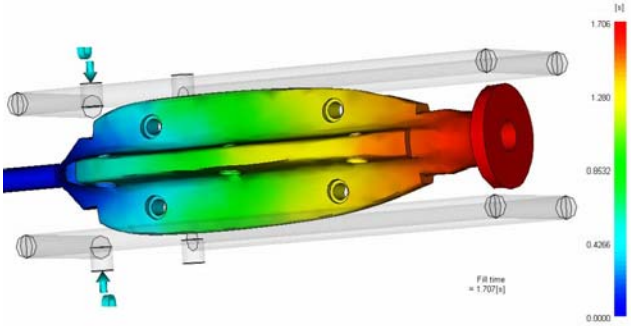

Fig.6 – Filling time

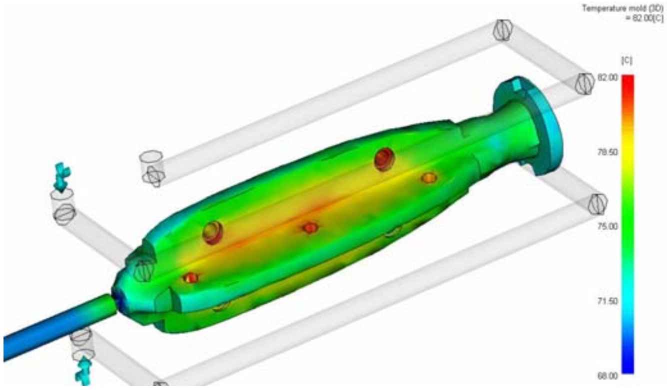

Fig.7 – Mould temperature

8. CONCLUSION

This contribution tries to show how to design the cooling system with usage of the analytic method and finite elements method. The results from the analytic calculation and mold – flow together shows that the part thickness is very high and the shrinkage will be very high. This has to be evaluated during the mould cavity dimensions construction. The choice of the cooling channels geometry seems to be OK. The difference of the cavity wall temperature about 10 °C is for such a complicated shape of the part success. The real temperatures and behavior of the process will be tested when the tool will be finished.

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SISTEM HLAĐENJA / ZAGREVANJA ALATA ZA INJEKCIONO PRESOVANJE

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REZIME

Kalupi za injekciono presovanje plastike imaju specijalne zahteve od sistema za hlađenje / zagrevanje. Inženjeri treba da prihvate i pridržavaju se pravila projektovanja kanala za hlađenje u kalupu. Rad prikazuje analitički način i metodu konačnih elemenata kao egzaktne i praktične alate u dizajniranju alata za injekciono presovanje.

Ključne reči*: Kalupi za brizganje, Dizajn, Sistemi hlađenja*