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Optimization of a Cooling System Design in a Complex Injection Mold

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***Abstract* - Complex manufacturing process such as additive welding is a very expensive procedure able to make every possible cooling circuit. This type of cooling is called "conformal cooling channels". This paper presents a cooling system design optimization process through three steps. It shows a design solution which is much cheaper and faster to manufacture than the conformal cooling system. Qualitative contribution will be shown to give the reader a feeling of the degree of cooling improvement by each design step. One of the problems solved and shown here is the assembly of cooling fountains in two sliders of the mold. The design takes into consideration the complex shape of the parts and their manufacturing on a 5-axis and 3-axis CNC milling machine, different loads of the sliders related to their movement, structural loads and high temperature during the injection and ejection process.**

Keywords: Injection molding, cooling, analysis, 3D design, innovative solution, slider, structural integrity.

I. INTRODUCTION

Injection molding as a massive production process has expanded over the last couple of decades in the world's industrial production [1]. The most significant application is in food, construction and automotive industry. Injection molding is one of the most important and the most complex processes when using polymers. By polymer injection process, ready-made multi-functional products of extremely complex structure are obtained, made within close tolerance field. Such products may vary in sizes (from extremely small to large) and masses (from few grams to several dozens of kilograms) [2].

Injection mold design of polymers represents an enormous challenge for a designer in modern age. The designer is required to design a tool in a very short time that will be able to produce a large number of pieces (from 200 000 to 1 million), by using minimum expenditure of material, time, energy and money. Tools thereby should endure high temperatures and large loads, and products should be injected very fast, usable and with the demanded quality. The speed of injecting a part or the quality in sense of warpage, tolerances can be solved in the design process of tool. The key to solve the mentioned problems is to design a uniform cooling system. The importance of the cooling system lies also in the cooling time which is related to the number of parts that can be produced in one hour or one working day. Because of this a designer has to relay on his experience a lot and to use earlier solution from which he can build new innovative designs. However, mathematical models do exist focusing on individual segments, such as arrangement of pieces in molds, fluid flow, heat conduction, cost-effectiveness etc. Injection molding of polymers has reached its sudden expansion by the application of computers and CAD/CAE/CAM (**C**omputer-**A**ided **D**esign / **E**ngineering / **M**anufacturing) software packages, especially due to complexity of products. This paper gives an insight in a real industrial injection mold with the emphasis of design problems in cooling and the way of solving these problems.

II. FINAL DESIGN OF INJECTION MOLD RELATED TO WORK PIECE GEOMETRY

3D models of requested work pieces, produced of PP GF 30 (**P**oly**P**ropylene with Glass Fiber 30%) polymer, are shown in Figure 1. Models are referred as work piece #1 and work piece #2 and they are of very complex geometry. Based on these models, an injection mold was designed and therefore its design is very complex as well. This injection mold, shown in Figure 2, was designed to inject two different parts with one shot.

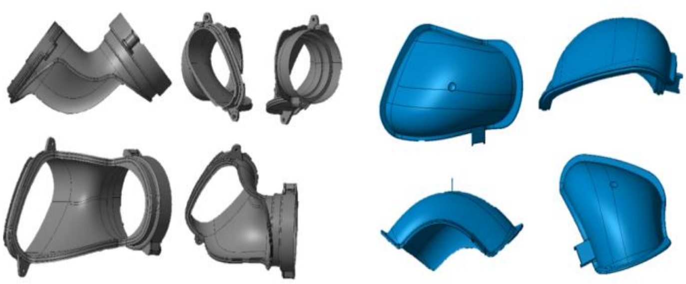

Figure 1: 3D model of the work pieces (work piece #1 in grey, work piece #2 in blue)

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The emphasis of the paper is the cooling of the work piece #1 with the more complex geometry. Figure 2 a) and b) show the moving side of the injection mold with all the sliders related to the work piece #1. Figure 2 c) shows the fixed side of the injection mold revealing its simpler design then the design of the moving side. Thereby its cooling is also simpler.

The second work piece takes the other half of the injection mold. This work piece has no special complexity in sense of the geometry that should be cooled in a special way. Therefore, the analysis of its cooling design is unnecessary to be performed in detail.

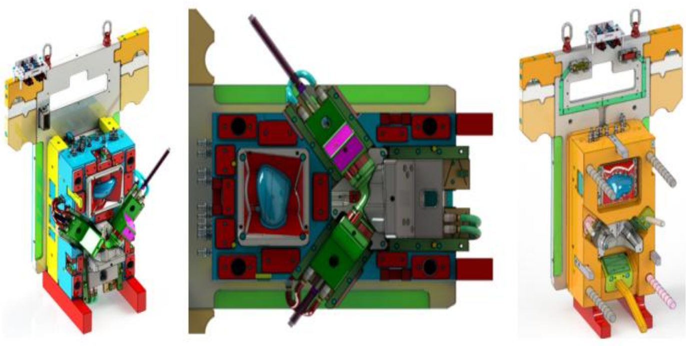

Figure 2: 3D model of the injection mold: moving side (a, b), fixed side (c)

III. DESIGN OF THE COOLING SYSTEM

Design of cooling channels is one of the most important segments in designing an injection mold. It controls the deflection and warpage of the final work piece. Cooling channels are very often drilled through the whole length of the plates and elements of the injection mold. Because of this, cooling channels are influencing many other segments of the injection mold design. Ejection pins, bolts and every other element of the mold has to be placed and organized taking into account the position of cooling channels and circuits in the mold. Too many cooling circuits may affect the structural integrity of the injection mold.

Related to all this, until today, many new design solutions is invented to improve the cooling of the injection mold. Three different cooling solutions are shown below.

a) Cooling solution #1

This part of the paper outlines the first solution of the cooling channels arrangement, shown in Figure 3. This is a basic idea how the cooling should be solved for this injection mold. The variant is based on the part geometry and basic standards related to injection mold design [2-6].

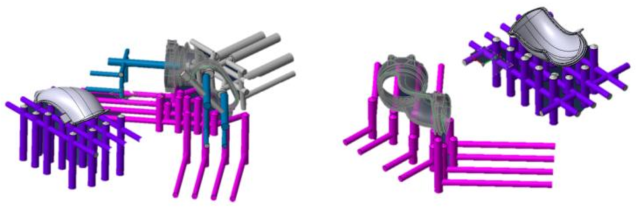

Figure 3: First cooling solution

As shown in Figure 3, this design of cooling is based on recommendations that can be found in standards and norms and given solution of standard injection mold part manufacturers. The problem with this design is that it is based on vertical bores called fountains. Therefore, there is a field of cooling points, but not cooling lines which is expected from a cooling channel. The best cooling system should have an area form surrounding cooled work pieces. The distance between the cooling area and the work piece is expected to be 10 to 15 mm. It holds the temperature on both sides of work pieces uniform and their values close to each other. With this kind of design, it is easy to bring the fountains 10 mm to the shape of the work piece, but only at a point where a lot of cooling channels are expected to be added in the form of fountains in order to approximate an area form of cooling. Thereby the structural integrity of the mold plates is decreased. The structural integrity of an injection mold cannot be jeopardized, because the plates are subjected to multiple types of load. This will lead to fail of the injection mold to produce necessary amount of parts, which is one of the most important properties of the injection mold.

b) Cooling solution #2

Figure 4 shows the second variant of the cooling system. This is an improved variant in reference to the previous. The design is also based on the work piece geometry and basic standards related to injection mold design [2-6]. The improvement on this design is mainly based on work piece #2. There are no fountains in the cooling of the moving side for the work piece. Cooling for the hot runner of the work piece #1 was added. Also fountains for the first part in the moving and fixed side are distant from each other, thereby increasing the structural integrity of the injection mold and simplifying the arrangement of the ejection pins in the moving side. This is also necessary for the work piece #2 in the fixed side, because it is directly injected and some space for the hot runner is needed. Further improvement is made in the slider cooling. There are now three fountains on one slider (turquoise in Figure 4). The problem still remains on the other slider (red in Figure 4), as one fountain is 30 mm away from the nearest work piece surface.

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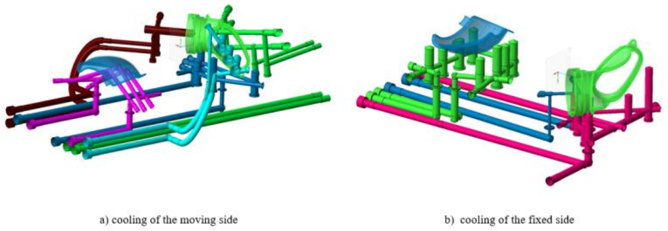

Figure 4: Second cooling solution

Figure 5 shows the sliders cooling improvement and the potential problems necessary to be improved in the next step.

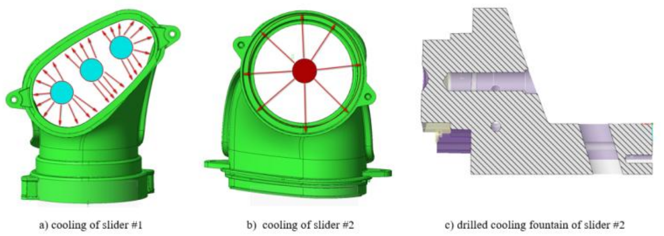

Figure 5: Cooling of sliders

Arrows are showing the connection between the cooling channel and the nearest surface of the work piece. Slider #1 has closer and better arrangement of cooling than slider #2. The regions of slider #1 between the cooling fountains are showing short segments of the work piece where the cooling is non-uniform. Cooling channels of both sliders are eccentric to the line of symmetry (slider #1) or center (slider #2). The drilling of these fountains is simple and easy to manufacture.

Figure 6 shows cooling of slider #3, which differs from the design in the first solution (colored in grey in Figure 3a). This design is simpler and easier to manufacture, but has less cooling channels. Due to this, channels are more distant from the work piece surfaces. Figure 6 also reveals the cooling circuits of slider #1 and #2.

From the comparison and comments marked above, the improvement of the previous solutions, leading to solution #3, will be focused on the slider cooling. The cooling of the work piece #2 in the moving side and fixed side of the injection mold is solved and optimized. Also the cooling of the work piece #1 in the fixed side is optimized.

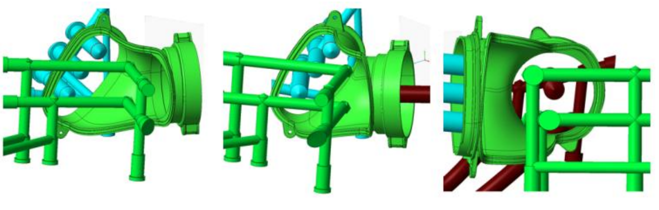

Figure 6: Cooling of slider #3

c) Cooling solution #3

Figure 7 shows the third solution of the cooling system in a final form with all cooling elements. This is an improved solution in reference to the first and second variant with the main emphasis on the cooling of sliders. Other segments of the cooling are a bit more adjusted to the other elements of the mold like bolts, threads, ejection pins etc. These designs are innovative to every other design and non-existing in any literature. They are based on the fundamental cooling designs making them easy to manufacture. The improvement of this design is mainly based on work piece #1 as more complex work piece. Figure 7b) shows the work piece #1 and its cooling system. The focus is on the cooling of slider #3 with view from the opposite side than in Figure 7a).

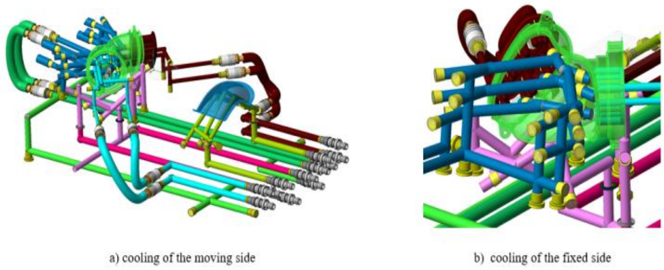

Figure 7: Third cooling solution

Figure 8a) shows the cooling of sliders #1 and #2 together, whereas Figure 8b) and Figure 8c) are showing perpendicular views of these cooling circuits with the basic idea of this cooling design improvement.

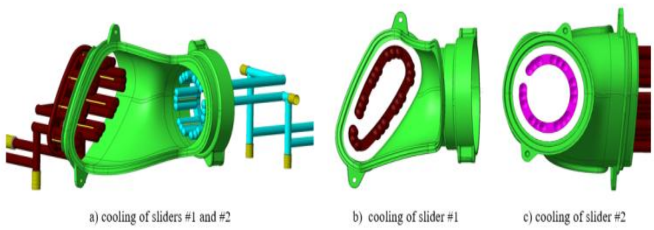

Figure 8: Cooling of sliders #1 and #2 in variant #3

The cooling circuits follow the shape of the part and therefore offer uniform cooling. The shape is easy to manufacture with 3-axis CNC milling machine. This manufacturing process is cheaper and faster than additive welding used for conformal cooling channels.

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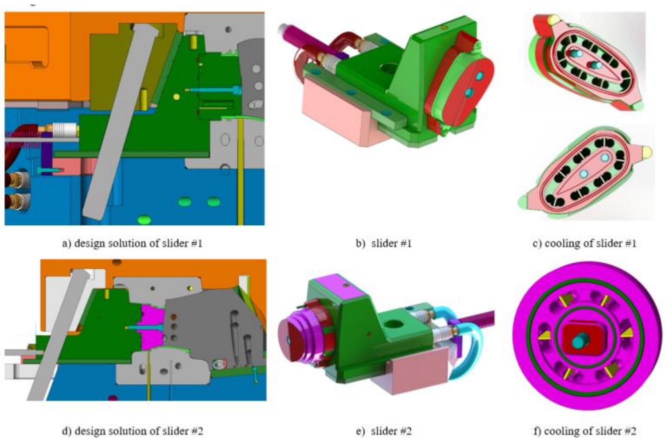

Figure 9: Design solutions of sliders #1 and #2 in variant #3

Design solution of the slider system assembly is shown in Figure 9. Segments a) and d) show the cross section of the assembly. The shape of the work piece, the core, is attached with bolts to the slider. Segments c) and f) outline O-rings in green and bolts in light blue. The benefit of this design is also the possibility that the core is changeable after some time of use. This is important as injected material is PP GF 30, having 30 % of glass fiber. This percentage of glass fiber causes high wear out of the cavity and core of the injection mold. The centering of these core inserts is performed by rectangular shape in all three directions. Segments b) and e) show the whole assembly of the sliders in 3D.

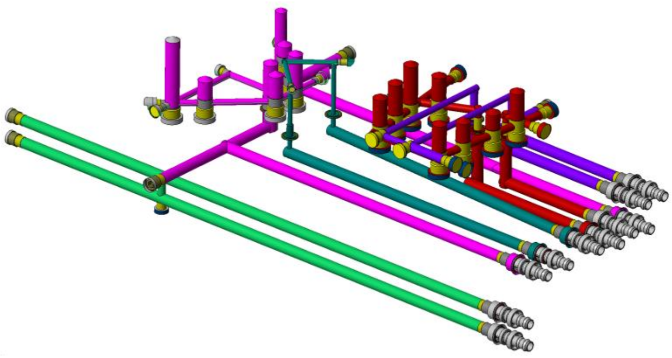

Figure 10: Cooling of fixed side of the injection mold - variant #3

Figure 10 shows the cooling of the whole fixed side of the injection mold. An additional cooling circuit (purple) was added for the work piece #2, cooling its middle region and the hot runner nozzle. This also represents an improvement compared to the first and second variant.

IV. DISCUSSION

Designing the cooling system of an injection mold requires several factors to be taken into consideration influencing the injection mold and the injected part. These factors are the structural integrity of the mold, the uniformity of the cooling, manufacturing cost, cooling of the hot runner, as well as assembling complexity of the whole mold. These factors are related to each other in the way of achieving cooling uniformity by increasing the number of cooling circuits. On the other side, this decreases the structural integrity of the injection mold and making it impossible to assemble with other segments of the injection mold as ejection pins, bolts etc. On the contrary, decreasing the number of cooling channels or arranging the cooling circuits in a wrong way, the uniformity of cooling is impossible to be achieved. This will cause deflection and warpage of the work piece and the geometric tolerances of the part will be far from the customer demanded. [7-9]In this design process all those factors are taken into account and the final shown solution reached the goal that all factors were optimized.

TABLE I
Advantages and disadvantages of analyzed cooling solutions

Solution number	Structural integrity	Uniformity of cooling	Cooling of the hot runner	Assembling complexity	Manufacturing cost
0	**Good**	**Excellent**	**Excellent, if used**	**Low**	**High**
1	**Bad**	**Very good**	**Good**	**High**	**Middle**
2	**Very good**	**Very Good**	**Missing for piece #2**	**Low**	**Low**
3	**Very good**	**Excellent**	**Excellent**	**Low**	**Low**

Table 1 shows all these important factors necessary to be met for the solutions shown in previous sections. Solution number 0 refers to the conformal cooling.

IV. CONCLUSIONS

Tools design in practice is mostly based on designer's experience. The reason for this are the short deadlines often set to the injection mold designers. The experience of the designer is related to their intuition that they developed during the time spent on designing, analyzing, calculating, doing optimizations, tryouts etc. This intuition, which is based on knowledge related to appropriate field, is a great tool when engineers are solving real problems. Many ideas that they come up with are based on what they did earlier or saw from earlier problems. This paper outlines the procedure how engineers transit from basic solutions to more advanced ones using their combined knowledge of many disciplines as mechanics, design, heat flow etc.

The contribution of this paper can be summarized as follows:

- Analysis commenced from real injection mold and was further used to produce complex parts;

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- Problems expected to occur in an injection mold were commented and shown;
- Procedure outlined the path of solving encountered problems where step by step approach was explained;
- Innovative design solution of slider cooling was offered.

Based on this paper, future work will consist on mathematical modeling of such problems offering appropriate quantification and contribution to the improvements made for every variant analyzed here.

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Dzanko Hajradinovic is Senior Research Assistant in Department of Mechanics at Mechanical Engineering Faculty of the University of Sarajevo, Bosnia and Herzegovina. He was awarded as the best student in his generation with the golden badge of the University of Sarajevo. He has published 1scientific paper in scientific journal, as well as participated in 2 scientific conferences. He has experience as an injection mold and deep drawing tool designer for 4 years. He worked as an R&D engineer for 3 years in the field of High Voltage Circuit Breakers. Currently he is working on his PhD thesis in the field of vibro- impact systems.

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