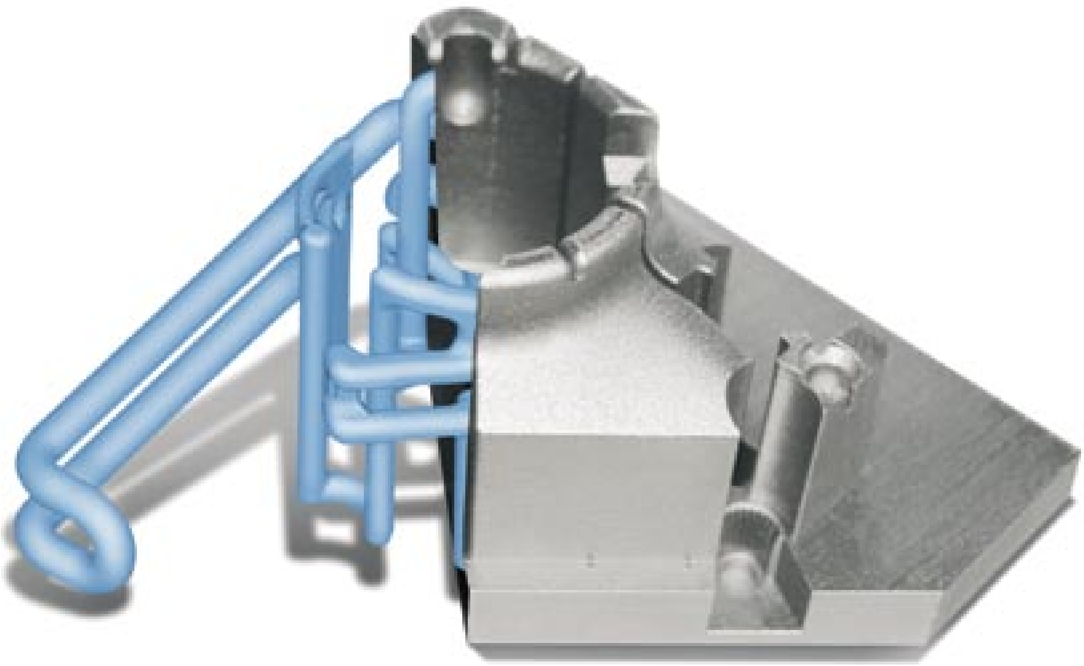
Any shape. Anytime. Anywhere.

Whitepaper

Optimised mould temperature control procedure using DMLS

Siegfried Mayer (EOS GmbH)



Courtesy of Fennel GmbH & Co. KG

e-Manufacturing Solutions

EOS GmbH Electro Optical Systems, Robert-Stirling-Ring 1, D-82152 Krailling/Munich
Phone +49 89 893 36-0, Fax +49 89 893 36-285, **www.eos.info**

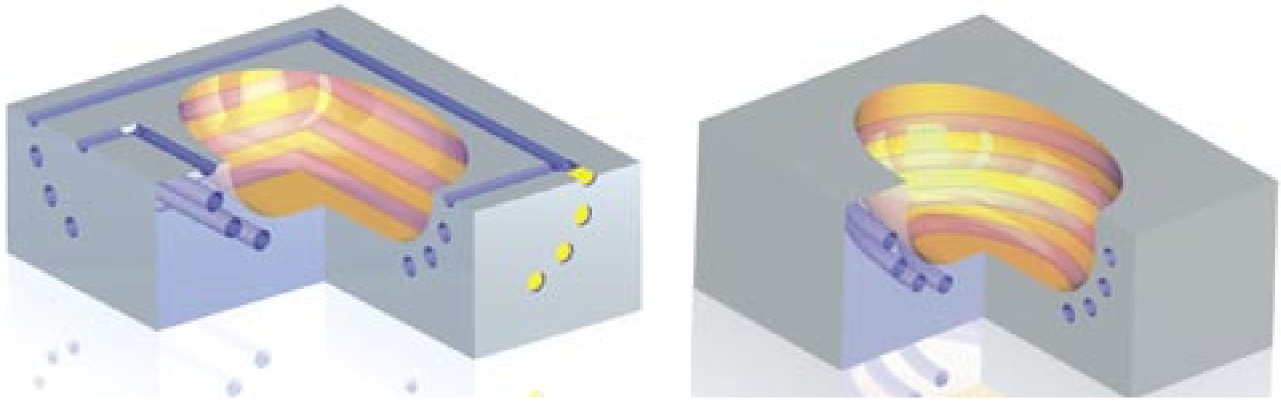
1. Introduction

EOSINT M systems produce solid metal parts by locally melting metal powder with a focused laser beam layer by layer. This automatically creates the final geometry from 3D CAD data. This method is called Direct Metal Laser-Sintering (DMLS). Depending on the material used and process parameters applied, this method allows for a wide range of part properties. Producing layer by layer allows for manufacturing highly complex geometries directly from electronic data with unique freedoms of design. DMLS can make EDM and milling obsolete in many cases, especially with complex part geometries where slides, inserts or other tool components with complex characteristics are required.

Since 1995, tooling has been the major application for EOSINT M technology. This application, called DirectTool, allows the manufacturing of tooling inserts and components in a timely manner, due to a tight process chain (Rapid Tooling). By continuously improving the technology and through the market introduction of the EOS maraging steel MS1 (which meets the high requirements of tool making for serial production), other applications such as series tooling and die casting became possible. On top of the value of short turn-around times additional value was created by the unique geometric freedom of design: "Advanced tooling".

One of the relevant "Advanced tooling" applications is the integration of conformal cooling channels. This helps to improve both the quality and economics of injection moulded parts. Today tools produced by EOSINT M are used to produce millions of parts in injection moulding operations or many thousand metal parts in die casting.

Figure 1
Conventional heating/cooling channels (left), Conformal heating/cooling channels with DMLS (right)



2. DMLS allows for almost any shape in heating/cooling channels and thus improves effectiveness of cooling

Conformal cooling with DMLS helps achieving these improvements and advantages:

» In terms of tool geometry

- Routing options for cooling channels are almost infinite. This makes it possible to create an ideal cooling channel in a well defined distance to the cavity. A conventional drilled cooling mechanism can not achieve this (Figure 1).
- Cooling channel cross sections can take almost any shape (e. g. oval vs. round) (Figures 7, 8). Turbulence of the coolant (the desired high Reynolds number) within the system can thus be controlled by actively choosing different cross sections and by switching between different cross sections. As a consequence, turbulence inside of the coolant is generated, close to cavity along the whole path of the channels. A bended path should improve in most of the cases this effect.
- Changing cross sections or forking the cooling channel can easily be done without splitting up the form (Figure 8). This allows for additional heat/cooling advantages in areas that cannot be reached by conventional methods.

» Quality in the process of injection moulding

- A more effective mould temperature control system saves time and costs in the process of injection moulding
- Quality of injection moulded parts is improved by better control of the injection moulding process. Warping and sink marks are minimized by evenly cooling out the plastic melt thus minimizing internal stress. Scrap rates are reduced or eliminated. Avoiding internal stresses helps to produce better parts with the same amount of required material. Certain geometries are only possible to manufacture at required quality standards with conformal cooling.
- Even combined systems with separated cooling and heating channels are possible or the split between main systems (for the control of the global temperature) and specific systems (for the handling of close to cavity critical temperatures) can be performed with DMLS. This opens up potential for future applications.

» Process costs

- Heating/cooling at critical parts inside the tool, which cannot – or only hardly - be reached by conventional methods, becomes feasible (e. g. long and lean cores, areas around hot-runners or small sliders). Using special copper heat conductors or other complex measures becomes obsolete.
- If necessary, it is possible to undercool mould cavities, thus reaching optimal cycle times by minimizing cool down times in tooling cavities.
- An evened out temperature level can help to improve tool life time. This becomes relevant especially in die casting tools that are exposed to extreme temperature variations.

Conventional cooling has the following drawbacks:

» The distance from cavity to cooling channel differs as only straight line drilling channels are possible (Figure 2) and as a consequence the heat dissipation cannot take place uniformly in the material. This results in ...

- Uneven temperature levels on the cavity surface.
- Uneven cooling-down processes resulting in internal stresses and thus negative impact on part quality (warpage).
- Actively influencing cooling-down processes inside the melt can often not be achieved.
- On top clogging of dead drilling ends creates areas with zero flow velocity thus facilitating dirt agglomeration. The drilling procedure itself is not without certain risks: in case of deep drilling there is always a danger to hit ejector holes (wandering drill), or the drill can even break. As a consequence, the whole mould insert could get unusable.

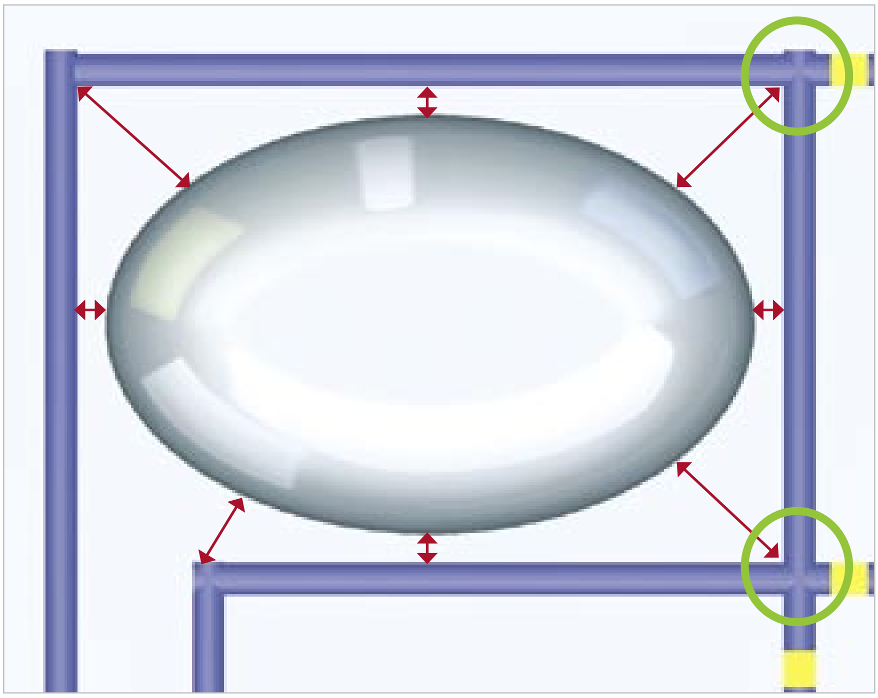
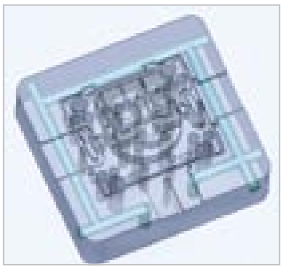


Figure 2
Conventional tooling mould temperature control. An uneven energy conductance is obvious in these cases. In the dead areas in front of the threaded plug that are not passed through (marked green), dirt deposits accumulate, which leads to a steady decline of the general flow (unnecessary pressure loss)

3. Case studies[1]

Maximum value created by DirectTool is optimizing cooling channels thus conditioning tooling temperature, which enables an uniform temperature level for the mould. This temperature level is influenceable in order to achieve on the one hand a lower temperature for quicker cooling or higher temperature for better product surface quality on the other hand. Therefore it has to be decided in every single case between the advantages of a reduced cycle time (=> process speed) and the moulded part quality (=>scrap rate because of warpage, better surfaces). This compromise has to be taken over into the tool and mould temperature control system design and the right choice. Conventional cooling channels are drilled into a tool. This limits design to straight lines, easily accessible by a drill. Tooling cavities can pose limits to position and routing of conventional cooling channels. With DMLS cooling channels can be positioned freely. Cross sections can be optimized to mould temperature control requirements.



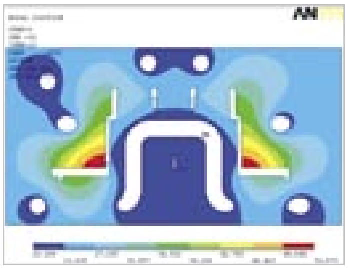


Figure 3
Electric cover
Left: Conventionally drilled cooling channels
Middle: Optimized conformal cooling
Right: Simulated temperature distribution within tool
Courtesy of PEP, Legrand

Studies and examples have shown the benefits of optimized cooling. Theoretical and practical research by PEP - Pôle Européen de la Plasturgie, Oyonnax Cedex achieved a drop in tooling temperature by 20°C thus reducing cycle time by 20 seconds. LBC- LaserBearbeitungsCenter, Kornwestheim reduced cycle times by up to 60 % in one case and reduced scrap rates from 50 % to zero by optimizing tooling temperature with DirectTool.

The project shown in Figure 4 avoided warpage in spherical injection moulded parts. The product, a give-away golf ball to be produced in large quantities at low costs, required blow moulding extruded PP combined with the injection of an elastomer. An additional technical benefit could be easily integrated, thanks to DMLS: usually the main challenge with this kind of form is about the venting of the tool which can, in the worst case, lead to deformed golf balls. The solution of this problem was the integration of venting channels with almost invisible openings towards the cavity. Thanks to the opportune choice of the process parameters it was possible to achieve two main objectvives: on the one hand the pressure can escape and on the other hand the channels do not clog up.

Figure 4
Golf Ball blow-mould
Left: Conformal cooling
Middle: Venting channels (Green)
Right: DirectTool cavity
Courtesy: Es-Tec, DemoCenter

As can be seen, the volume of the cavities could be minimized which helped reducing building time and thus costs of the DMLS tool. Eight cavities were combined making up for a four cavity tool, producing more than20 million golf balls. Building the tool only took 50 hours. The conformal cooling channels increased the productivity by 20 %.

Figure 5 shows three examples for the usage of conformal cooling channels. Figure 5a shows a tool for blow-moulding PE bottles. Cycle-time and productivity of this type of tool are limited by the time it takes to cool down the bottle necks as wall-thickness reaches a maximum there. In this case-study small DirectTool inserts with conformal cooling channels were built and integrated into a conventionally manufactured tool in order to extract the heat from these parts more quickly. The inserts reduced cycle times from 15 down to 9 seconds. This enables a 75 % increase in productivity for a 4 bottle blow mould without sacrificing on quality.

Figure 5b shows a cooling pin for cooling an injection point, which is a classical hot spot. Conformal cooling in this case reduces cycle times by two thirds. 5c depicts a core with spiral conformal cooling channels inside the dome. By conventionally milling the lower part of the tool and limiting DMLS to the part with conformal cooling, costs were reduced. 0.3mm machining allowance was added for finish-machining of the outer surface.

Figure 5
Cooled tooling inserts.
(a) left: for bottle necks in a blow mould
(b) middle: core for cooling a gating point
(c) right: hybrid core containing conformal cooling channel built on top of a machined base.
Courtesy of SIG Blowtec, Es-Tec, DemoCenter, LBC

4. Designing DMLS mould temperature control systems

Design recommendations for the layout of heating/cooling channels with DMLS are the same as the ones given for conventional designed channels: they are both based on the plastic recrystallization and heat conductivity theories[2], with the necessary adaptations to conformal mould temperature control systems on the one hand and the advantages of DMLS on the other hand (for example the possibility to change the cross section along the channel path). The ultimate objective is the creation of a mould temperature control system, which enables a constant and adapted temperature level for the material, during the running injection moulding process (observe recommendations of the material manufacturer), on each point of the moulding surface. In order to achieve this result, the channel diameter should be chosen depending on the distance between the heating/cooling channel and the cavity. Provided that the design for the moulded part is correct, the product can recrystallize uniformly and efficiently in the mould after the injection phase, which improves the quality (no internal residual stress means warp-free product with longer life cycle) and reduces the cycle time.

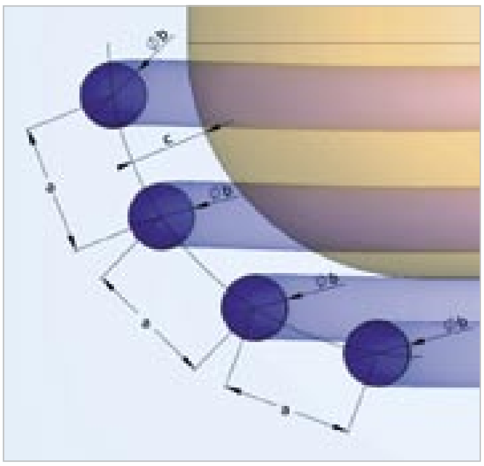


Figure 6
optimal design of a three dimensional channel system

Wall thickness of molded product (in mm)	Hole diameter (in mm) b	Centerline distance between holes a	Distance between center of holes and cavity c
0 - 2	4 - 8	2 - 3 x b	1.5 - 2 x b
2 - 4	8 - 12	2 - 3 x b	1.5 - 2 x b
4 - 6	12 - 14	2 - 3 x b	1.5 - 2 x b

According to experience, the optimal diameter should be chosen between 4-12 mm (depending on the design of the product). These values are preferred values, to be used in ideal cases, as in practice sometimes tool inserts are too slim to make it possible to follow exactly this rule (for example a closely placed pair of ejector pins, thin walls etc.). In case of such complex geometrical conditions it can be necessary to design much smaller diameters, for example when eliminating a hot spot. DMLS can build channels down to 1 mm diameter, but it should be taken into consideration that such fine channels can only be put into service with specially treated fluids in order to avoid clogging. Simulation software helps to find the right layout in such critical cases.

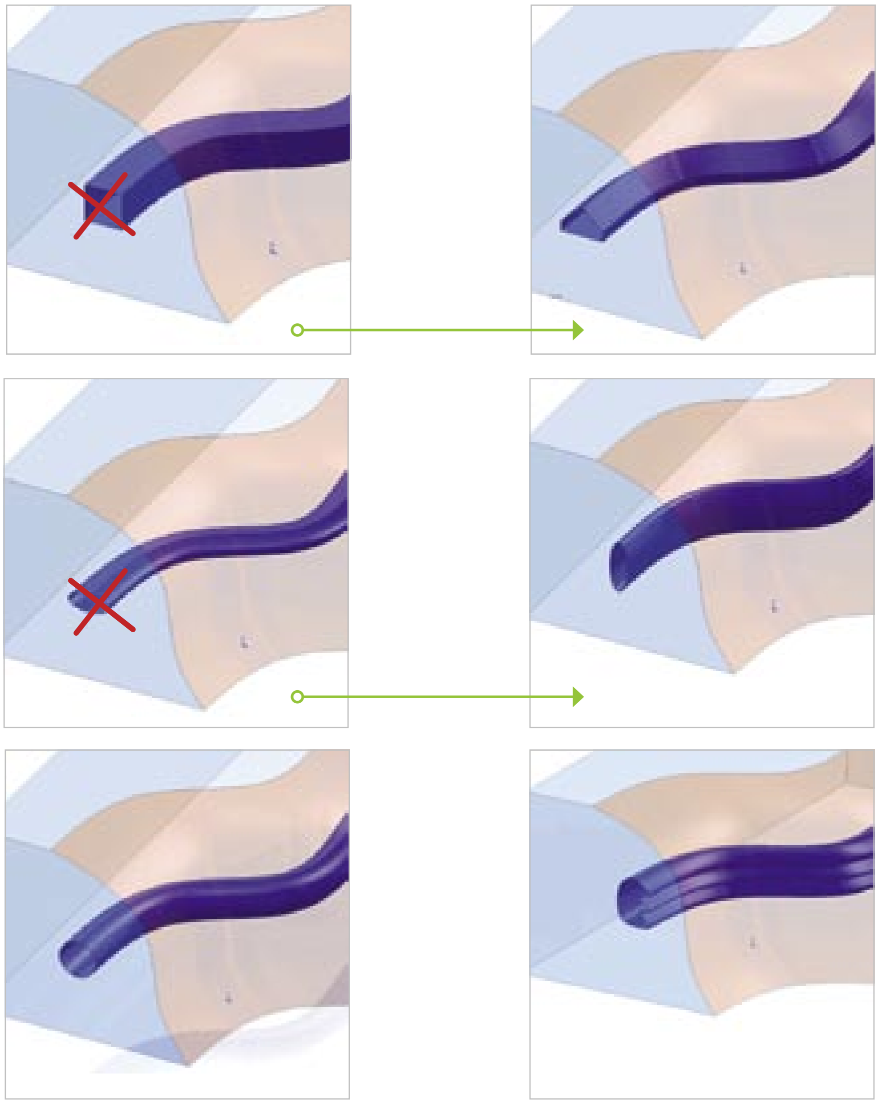


Figure 7
With DMLS it's possible to vary the channel cross section shape of the manufactured tool inserts: additionally to circular ones, the designer can choose complex other shapes. The feasibility criterion supposes a cross section, which is self supporting. This means the angle of overhanging areas should be above 40° to horizontal. On the last picture the cooling performance can be increased due to the ribbed shape and the higher expected turbulence in the channel (higher Reynolds number).

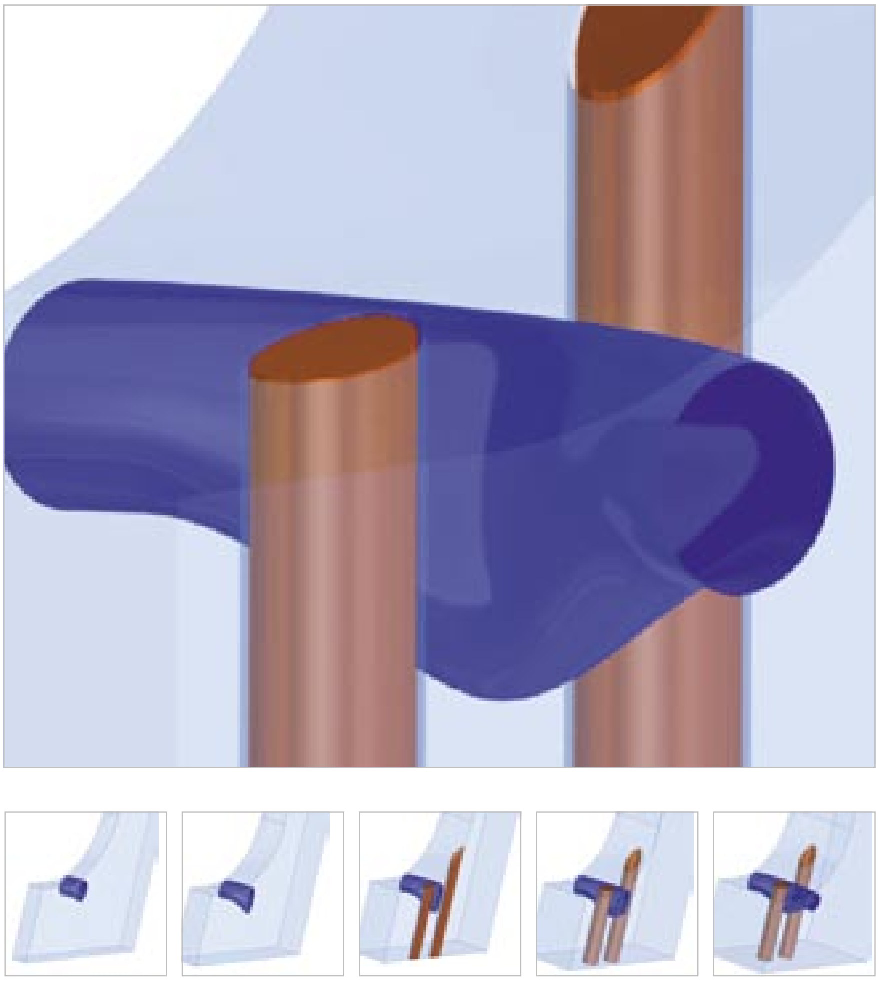


Figure 8
the freedom to change the cross-section shape enables the DMLS user to implement new solutions: in this illustrated case, the preferred design does not require a new channel layout. In this example two ejectors are bypassed in the space between without pushing the remaining wall thickness to a critical limit. Absolute condition: the cross section area along the channel has to be kept constant, to avoid flow braking effects.

5. Conclusions

DMLS opens new frontiers for the implementation of very efficient heat/cooling systems and also offers the designer extended possibilities for the manufacturing of high performance tools – without having to consider the many limitations which characterize the conventional process. The real additional challenge for the integration of this kind of system is to be found in the first steps of the project, that is to find the correct design of the channels. The manufacturing process of the mould inserts is not influenced by the complexity of the chosen cooling solution because the DMLS system simply builds the channels at the same time, without having any major impact regarding the jobtime. In view of all the advantages such systems offer, it is not justifiable to do without them in the injection moulding production, considering the fact that the main part of the costs in large scale serial production occurs at this stage. In order to reach the maximum efficiency in service (and in order to foresee the effect during the mould design) the use of adequate simulation software and respectively analysis software (based on the control volume FEM) is highly recommendable. According to the current level of knowledge, there is no analysis software which is able to simulate three dimensional heating/cooling systems with different channel cross section shapes. But considering the complexity of the mould temperature control requirements, the results of simulations made with the approximation of the channels to a circular shape should be sufficient for a first approximation.

References

[1] Mike Shellabear, Joseph Weilhammer: Tooling Applications with EOSINT M.
In: EOS Whitepaper, Krailling, September 2007.

[2] Olaf Zöllner, Optimised mould temperature control.
In: ATI 1104 d (Application Technology Information),
Plastics Business Group, Bayer AG, Leverkusen, 31.01.1999.

About the author

Siegfried Mayer started at EOS in 2000 as application engineer. He has more than 14 years experience in the tooling sector and has been responsible, since the beginning for tooling and moulding customers and for the tooling application area.

e-Manufacturing Solutions

EOS GmbH Electro Optical Systems, Robert-Stirling-Ring 1, D-82152 Krailling/Munich
Phone +49 89 893 36-0, Fax +49 89 893 36-285, **www.eos.info**