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(54) **Piston with optimum cooling effectiveness for cold-chamber die-casting systems**

(57) Invention relates to a piston for die casting comprising a piston body, which is a single-element object, and a thermal regulation system integrated into or built inside the piston body, wherein thermal regulation system includes a passageway enabling flow of fluid for temperature regulation of the piston. There are no limitations on the passageway spatial position within physical boundaries of the piston body. Innovative solution ena-

bles optimization of the piston cooling effectiveness throughout the casting cycle.

The proposed piston with integrated cooling is generally produced as a single-element product utilizing a particular manufacturing technology. Based on the piston design simplicity the invention also assures its cost-effective production.

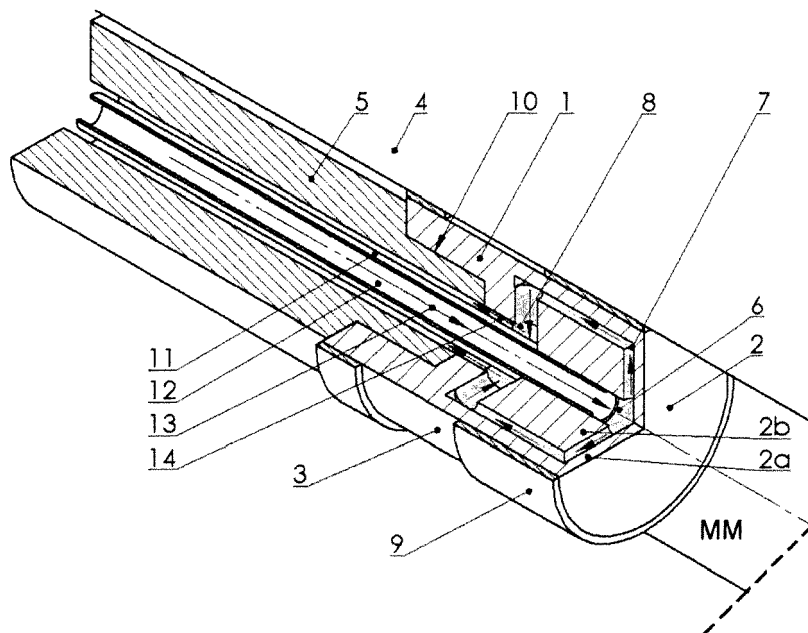


Fig.1. Schematic of the novel die-casting piston with integrated cooling system.

Description

Background and Summary

[0001] A casting piston disclosed in this invention can be utilized in any die-casting or industrial application other than die-casting, including but not limited to cold-chamber pressure die-casting of aluminum or magnesium alloys. Although there are numerous possibilities for application of the piston subject to this invention, explanation in the present work is primarily based on examples in cold-chamber pressure die-casting process.

[0002] In cold-chamber die-casting molten metal is poured into a shot sleeve and from there pushed by the casting piston mounted on a shot rod into a die, where molten metal is solidified to form a cast part of desired geometry. Molten metal in this case refers in particular to, but it is not limited to molten aluminum or magnesium, both having relatively high processing temperatures. Further description of die-casting process and specific technical terms defining different components of casting systems shall not be provided in this exhibit, as these can be found elsewhere.

[0003] Components of casting system in direct contact with molten metal are subjected to extreme thermal loading. The piston pushes molten metal to the die and provides sufficient pressure to molten metal to fill the die and solidify with no porosity defects. The piston, in particular its front surface, is exposed to both extreme thermal and mechanical loading. The first is due to direct piston contact with molten metal, whereas the later is due to high pressure exerted to the piston front surface at final stages of casting cycle. Optimum cooling of the piston is critical in assuring best quality of cast part and improving production performance.

[0004] Optimum cooling of the piston is achieved by determining cooling intensity at any particular part of the piston as a transient function, with objective to maximize the cast-part quality while minimizing production cycle-time. Cooling intensity is a parameter dependent on a series of controllable, say independent variables. It is simply determined by heat capacity rate of cooling fluid (CF) multiplied by difference in CF inflow and outflow temperature. Heat capacity rate of CF is calculated by multiplying its mass flow rate and its specific heat. The specific heat is defined by selection of CF, whereas both the mass flow rate and the inflow temperature are defined by setup of CF control unit. The CF outflow temperature, on the other hand, is directly influenced by cooling effectiveness of the piston, which can also be understood as a piston design and material parameter. This also means that cooling intensity of the piston is determined by the piston cooling effectiveness, heat capacity rate of CF and the inflow temperature. It must be, on the other hand, equal to heat energy passing from molten metal (MM) to CF in a given time.

[0005] Cooling effectiveness of the piston is thus its ability to transfer heat energy from MM to CF. It directly

depends on the piston design and materials utilized. It may be expressed as a ratio between the actual transfer of heat energy and the maximum possible transfer of heat energy from MM to CF, both at given CF inflow temperature and flow parameters.

[0006] Generally, the heat transfer from MM to CF is determined by: (i) difference in temperature between the piston front surface and MM, surface area of the piston front, and the corresponding heat transfer coefficient, (ii) difference in temperature between the piston front and the surface a cooling channel inside the piston, the corresponding distance, and coefficient of thermal conductivity (CTC) of the piston material, and (iii) difference in temperature between the cooling channel wall and CF, surface area of the cooling channel, and the corresponding heat transfer coefficient (CHT).

[0007] The piston cooling effectiveness can be improved by finding new solutions in the piston design primarily influenced by the following independent parameters: (i) surface area of the cooling channels, (ii) distance between the piston front and the cooling channel surface, (iii) CTC, and (iv) CHT. CTC directly depends on selection of the piston-front material, whereas CHT depends on surface quality of the cooling channel. The other two parameters, surface area of the cooling channel, and distance between the piston front and the cooling channel surface, are directly influenced by the piston design.

[0008] Intense cooling that can be reached by the pistons with highest cooling effectiveness assists to shorten production cycle time and improve productivity. However, it may also result in premature solidification of casting metal before entering the die, which may also result in negative impact on casting performance and the cast-part quality. Therefore, it is decisive to optimize cooling of the piston throughout the casting cycle. Optimum cooling conditions of the piston normally require: (i) minimum cooling intensity in the pour and shot phase to keep MM at correct temperature and prevent its premature solidification; (ii) maximum cooling intensity in the pressurization phase to assist: (i) solidification of MM in shortest possible time, thus improve productivity, and (ii) the piston front-wall strength by lowering its temperature.

[0009] Die casting industry is generally using standard-type pistons that are simple single-part pistons, usually made of copper based alloys, with internal cooling (see Figure 6). An important development in the piston cooling intensity is achieved by Allper (US 8.136.574 B2) by increasing the piston internal surface area in contact with coolant in their multi-part piston. A step further is made by Brondolin (US 2012/0031580 A1) with generally the same multi-part piston. They improved cooling of the side piston walls by increasing surface area of direct coolant contact with the main piston body, which improved the piston cooling effectiveness. A general idea of making a cooling circuit built into a part of piston is presented in US2012/199305.

[0010] Furthermore, the gap between the piston and the shot sleeve can be sealed by different technical so-

lutions. Allper presented an invention of a sealing ring and demonstrated its advantages. Design allows MM to flow and freeze in the gap between the piston and the sealing ring, thus improving sealing effectiveness (see US 5.233.913). There are several versions dealing with technical details on fixing the ring to the piston body, preventing its rotation relative to the piston body, and design variations of grooves that get MM to the gap between the piston and the sealing ring (see US 7.900.552 B2 and US 2012/0024149 A1).

[0011] Multi-part casting pistons present a step forward in cooling effectiveness with respect to standard-type pistons. Nevertheless, there is room for improvement in the piston performance. Important design and technical advancements are required to reach its optimum thermal and general functional performance. Following are preferred technical provisions to obtain a casting piston with optimum performance:

(i) design the piston with optimum cooling effectiveness as a spatial and transient parameter; in other words, select material and design combination to achieve optimum cooling effectiveness for different piston surfaces as a function of casting cycle time;

(ii) develop fabrication process to produce the piston with cooling system of largest feasible surface-area positioned to a minimum possible distance from the front piston surface and/or side piston surface, all with respect to geometric parameters and required mechanical properties. The maximum possible transfer of heat energy from MM to CF is achieved, or in other words, the piston with highest cooling effectiveness is fabricated; i.e. maximum cooling effectiveness design (MCD);

(iii) develop flexibility in fabrication so that the piston with optimum cooling effectiveness is produced; it means that the piston cooling effectiveness can be anywhere between the two extremes: minimum cooling effectiveness of the standard-type piston on one hand, and MCD piston on the other;

(iv) define manufacturing technology to build a simple-geometry piston that allows accomplishment of above defined provisions (optimization of the piston thermal behavior), while assuring cost-effective production (avoid influence of design flexibility to production costs).

[0012] A single-element die-casting piston with integrated cooling system is presented in this invention. Single-element in this invention refers to the piston body. The piston may contain one or more sealing rings, which are either permanently bonded to the piston body or manufactured as replaceable parts. The invention described in detail in the following text provides solution to above defined technical provisions. Figure 1 to 7 show the novel

piston design and explain the invention.

Brief description of drawings

[0013]

- Fig.1. Schematic of the novel die-casting piston with integrated cooling system.
- Fig.2. Schematic of integrated cooling design in the piston front: (a) spiral design, (b) concentric connected circles, (c) radial lines, (d) random design network.
- Fig.3. Schematic of integrated cooling design in the side wall: (a) helical design, (b) series of circles, (c) linear, (d) random design.
- Fig.4. Section of cooling channel demonstrating possibilities to influence surface area of cooling system.
- Fig.5. Example of piston parts prepared for final manufacturing process: (a) machining of cooling system into inner part, and (b) machining of cooling system into outer part.
- Fig.6. Schematic of two cooling extremes: (a) ICS piston with maximum cooling efficiency, (b) standard-type piston.
- Fig.7. Plot demonstrating results of cooling optimization.

Detailed description

[0014] Figure 1 shows a die-casting piston and a shot rod assembly indicating an integrated system of cooling channels and the coolant path. The die casting piston (1) is a single-element cylindrical object with the front surface (2) in contact with molten cast metal (MM), the cylindrical side surface (3) in contact with the shot sleeve (4), and the central hole used to attach the piston to the shot rod (5). The piston has the coolant inlet (6), the integrated cooling system (7) and the coolant outlet (8). The piston may also have a sealing ring (9) that assist sliding contact between the piston and the shot sleeve and effectively seals the gap between the piston and the shot sleeve from entering MM. The piston is attached to the shot rod by thread or other type of known fixture (10) (a possible example is a bayonet type fixture). The piston and the shot rod assembly described in Figure 1 is generally a well-known setup widely used in casting industry.

[0015] The shot rod has an internal passage or central hole (11) used to transfer coolant to and from the piston. The coolant transfer can be accomplished in different ways. One example is installation of two separate tubes built into this central passage, one for coolant inflow to the piston and the other for coolant outflow. Figure 1 shows a widely used system of a single tube (12) built-in into the central passage. This central tube is of smaller diameter than the central passage and used for coolant inflow (13), which is in communication with the coolant inlet in the piston centerline (6), whereas the passage

between the shot-rod inner and the central tube serves for coolant outflow (14), and is in communication with the coolant outlet from the piston (8).

[0016] Invention relates particularly to the cooling system integrated into the piston body (7). Coolant inflow from the shot rod inflow-tube to the integrated cooling system (ICS) can be positioned as shown in Figure 1. Position of the coolant inlet to ICS is not particularly limited by this invention. ICS can be of any feasible geometry. Some examples are presented in Figure 2; (a) spiral, (b) series of connected concentric circles, (c) radial, or (d) any other cooling system geometry down to a random design cooling network. Cooling of the piston front surface may continue to the piston side surface in similar patterns. Figure 3 shows some possibilities of cooling system built into the side wall: (a) helical, (b) series of connected circles, (c) linear channels distributed around the circumference, or (d) any other cooling system geometry down to a random design cooling network. The coolant outlet is positioned depending on geometric features of ICS in communication with coolant outflow passage in shot rod. ICS design allows any feasible cooling channel cross-section geometry, which directly influences surface area of the cooling system. Figure 4 shows some possibilities, from (a) circle, (b) square, (c) rectangular, and (d) an example of particular geometry cross-section. For example, same characteristic dimension of the cooling channel gives in case (d) for about 35% more surface area compared to case (c).

[0017] A particular manufacturing technology, in our exhibit vacuum brazing, is used to obtain the piston subject to this invention. Figure 5 shows two parts with the pre-machined cooling system. The cooling system is machined by standard machining techniques to either surface of the piston inner part (15) or the piston outer part (16), or possibly to the both surfaces. These two parts are then assembled and fused into the single-part piston with ICS. Side where machining of the cooling channels is performed is selected solely based on machining preferences, as it does not influence the piston thermal behavior, as long as the material for inner and outer part have same thermal properties. The claimed invention is not limited to this particular manufacturing technology. Other manufacturing technologies, such as casting, metal printing, certain welding technologies or other technology may be used to obtain the results subject to this invention.

[0018] The cooling system subject to this invention can be made of any chosen pattern, cross-section geometry, and at any chosen distance from the piston front surface or the piston side surface, as long as stresses in the piston induced by thermal and mechanical loading throughout the transient are not compromising its structural integrity.

[0019] Main advantages of ICS are:

(i) it can be made of any feasible geometry (examples see Fig.2 and 3), as well as the channel cross-section geometry (see Fig. 4), in order to obtain the required

surface area and thermal response,

(ii) complete surface of the cooling system is in contact with the piston body and thus set in function to transfer the heat from MM directly to coolant,

(iii) the cooling channels can be positioned at any distance from the front piston surface and the side piston surface;

(iv) material of the piston front and/or the piston side with its heat conductivity properties can be selected based on desired cooling effectiveness;

(v) ICS can be designed to obtain spatially variable cooling intensity, as well as obtain particular cooling intensity at different casting-cycle phases.

[0020] ICS can be characterized by three main parameters (see Figure 1): A_c represents the surface area of cooling system, h represents distance from the piston front and/or the piston side to the cooling channel, and λ represents heat conductivity coefficient of the piston front and/or the piston side material.

[0021] Parameter A_f represents surface area of the piston front that is in contact with MM, thus heated surface subject to cooling. The piston may also be receiving heat from the side surface in contact with the shot sleeve, which generally depends on temperature of the shot sleeve inner surface.

[0022] Figure 6 shows two pistons representing limiting thermal-behavior cases. The piston with highest feasible cooling effectiveness, MCD, can be manufactured by bringing the cooling channels as close as possible to its front surface, h_1 , for the piston-front utilize material with highest possible thermal conductivity, λ_1 , and design the cooling channels with largest surface area possible, $A_{c1} \gg A_{f1}$ (see Fig.6(a)). The other extreme is the piston with no cooling, or for practical comparison purposes the standard-type piston with low cooling effectiveness, characterized by h_2 , A_{c2} and λ_2 , where $h_2 > h_1$, $\lambda_2 = \lambda_1$, and $A_{c2} \ll A_{c1}$ (see Fig.6(b)). The two limiting cases: (i) the new ICS piston and high cooling effectiveness, and (ii) the standard type piston, have significantly different thermal behavior with important influence to function of casting system.

[0023] For illustrating advantages of ICS pistons compared to standard-type pistons, numerical simulation of a conventional aluminum cold chamber die-casting process is performed. Figure 7 shows temperature at the centerline underneath the piston front surface, T , normalized by temperature of MM, T_{MM} , presented as a function of time, t , throughout one casting cycle, t_c , for: (a) standard-type piston made of material with higher thermal conductivity, such as copper; (b) standard-type piston made of material with lower thermal conductivity, such as steel; (c) an ICS piston with a moderate surface area of cooling system, A_c , and front surface made of copper, and (d)

the same piston as in case (c) with front surface made of steel. In case (a) the monitored point is at temperature T_s when filling starts, then the temperature rises to T_{max} at the end of pressurization phase, then, during solidification and idle phase the piston cools to the lowest temperature in the cycle $T_{min} = T_s$, before a new cycle starts. Comparison of cases (a) and (b), standard-type pistons, shows considerably higher temperature throughout the cycle for a piston made of steel. Cases (c) and (d), ICS pistons, have T_{min} at considerably lower temperature and T_{max} at higher temperature compared to case (a). Peak temperature T_{max} in cases (c) and (d) is shifted to the left, which means that peak temperature occurs sooner during filling phase compared to case (a). Presented facts reveal three important conclusions:

(i) T_{max} in case of ICS piston, (d), is significantly higher and occurs sooner in the filling phase than in case of standard-type piston, (a). High temperature of the piston front is supported by low heat capacity of the piston front, (2a), located between ICS and MM (see Fig.1). This phenomenon is beneficial for quality of castings and optimization of casting process as it prevents premature solidification of casting material;

(ii) temperature drop in case of ICS piston, (d), is drastic during the solidification phase, and corresponding T_{min} is significantly lower than in case (a). This is due to high cooling effectiveness of ICS piston and is extremely beneficial for improving casting productivity;

(iii) temperature response of ICS is simply controllable by appropriate selection of A_c , as well as other two critical parameters, h and λ , which permits to shift the T-t curve presented in Fig.7 to higher or lower temperatures based on parameters selected.

[0024] Significance of this invention is that selection of particular combination of the three parameters directly determines thermal response as spatial and/or transient function, and thus consents to directly perform piston thermal optimization. The three parameters are independent, with particular influence to system thermal response: A_c directly influences cooling intensity, whereas h and λ influence both cooling intensity and the temperature response time. The later depends on heat capacity (mass and specific heat) of the piston material between ICS and MM. Therefore h and λ can be utilized for optimization of cooling effectiveness as function of time. Design of the cooling channels can also be made so that spatial optimization of cooling is achieved.

[0025] Significance of this invention is also in highest flexibility of ICS design and thus ability for optimization of the cooling system for any casting application with minimum or no influence to manufacturing costs. The ICS piston shall be designed and manufactured by principles of optimum thermal regulation. The design for optimum

ICS setup is based on performed computational modeling analysis considering main casting parameters.

[0026] In general the piston shall be considered a heat exchanger that exports the heat from MM to CF. Term "cooling" used in this disclosure means that MM is cooled by CF. However, in optimum casting conditions there may be need for the fluid to heat the piston. Therefore, replacement of terms "cooling" and "cooling fluid" by terms "thermal regulation" and "fluid", respectively, generalizes the relevance of this disclosure.

Claims

1. A piston moving inside a shot sleeve of a die-casting press for pushing molten metal from the shot sleeve into a die, comprising:

a piston body (1), which is a single-element object (it is not an assembly of plurality of elements) having an outer cylindrical surface (3) facing the shot sleeve (4), a piston front surface (A_f) in contact with molten cast metal (MM), and a cavity or other geometric feature at the other piston end used to fasten the piston; and
a thermal regulation system integrated or built inside said piston body;

wherein said thermal regulation system includes a passageway enabling fluid flow for temperature regulation of the piston;

wherein said passageway is considered either one single channel or plurality of channels, with no limitations on said passageway spatial position within physical boundaries of piston body, and with no limitations on said channel cross-section geometry;

wherein said passageway comprises a fluid inlet or plurality of inlets and fluid outlet or plurality of outlets,

wherein said fluid inlet or plurality of fluid inlets are in communication provided by said passageway with fluid outlet or plurality of fluid outlets.

2. The piston as recited in claim 1, wherein said piston body is built out of plurality of pre-machined elements fused together to a single-element object, using but not limited to vacuum brazing technology;

wherein one of said pre-machined elements used to fuse the piston body contains the entire said thermal regulation system, or plurality of said pre-machined elements contain each a part of said thermal regulation system;

wherein said pre-machined elements are made of one material or plurality of different materials.

3. The piston as recited in any preceding claim, wherein the piston is mounted on a shot rod (5);

wherein said fluid inlet or plurality of fluid inlets in the piston are in direct or indirect communication with fluid inflow in the shot rod, and said fluid outlet or plurality of fluid outlets in the piston are in direct or indirect communication with fluid outflow in the shot rod. 5

4. The piston as recited in any preceding claim, wherein said passageway is filled completely or partially with material having thermal-conductivity properties different than said piston body. 10
5. The piston as recited in any preceding claim, wherein the piston is not limited to one single-element, but may consist of plurality of elements. 15
6. The piston as recited in any preceding claim wherein sealing between the piston and the shot sleeve is achieved by a single sealing ring or plurality of sealing rings attached to said piston body. 20
7. The piston as recited in claim 6, wherein said sealing ring or plurality of sealing rings are fastened to said piston body by a permanent bond and the bond is made by, including but not limited to welding, or said sealing ring or plurality of sealing rings are entirely constructed by welding. 25

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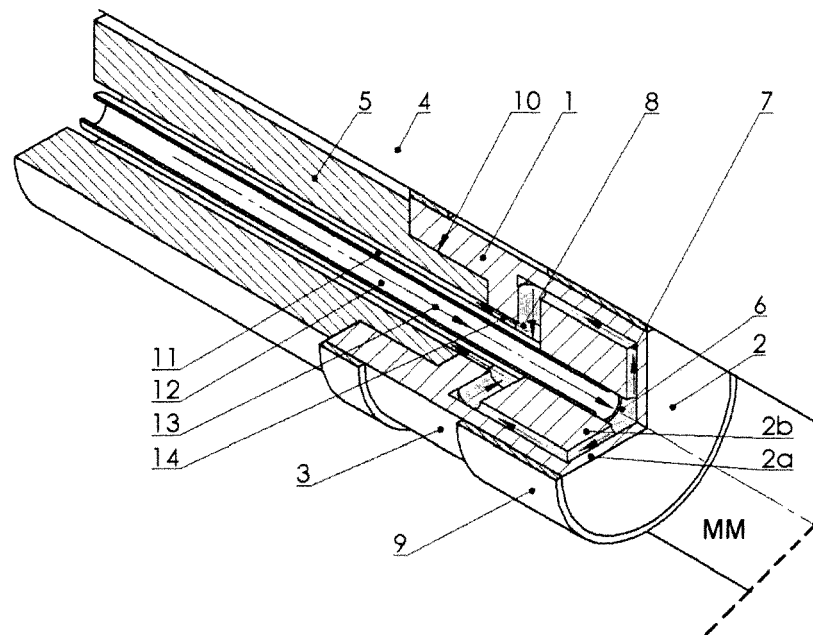


Fig.1. Schematic of the novel die-casting piston with integrated cooling system.

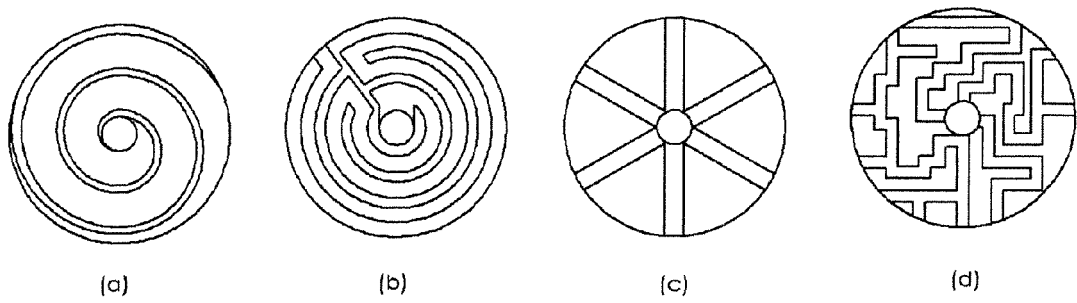


Fig.2. Schematic of integrated cooling design in piston front: (a) spiral design, (b) concentric connected circles, (c) radial lines, (d) random design network.

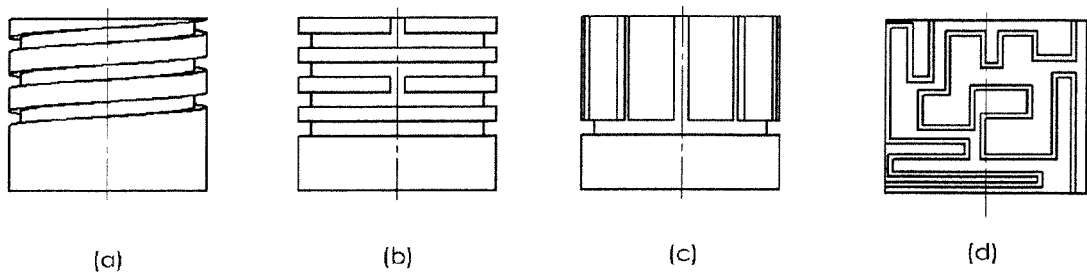


Fig.3. Schematic of integrated cooling design in side wall: (a) helical design, (b) series of circles, (c) linear, (d) random design.

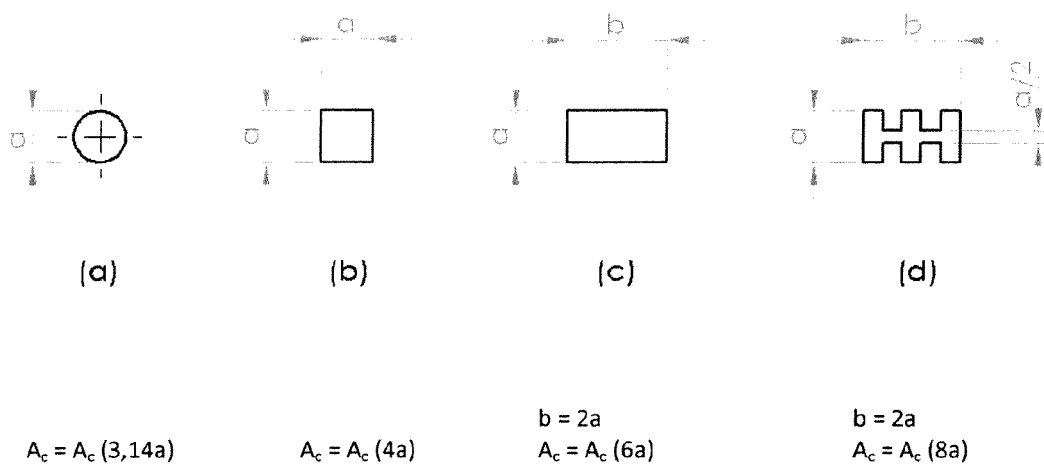


Fig.4. Section of cooling channel demonstrating possibilities to influence surface area of cooling system.

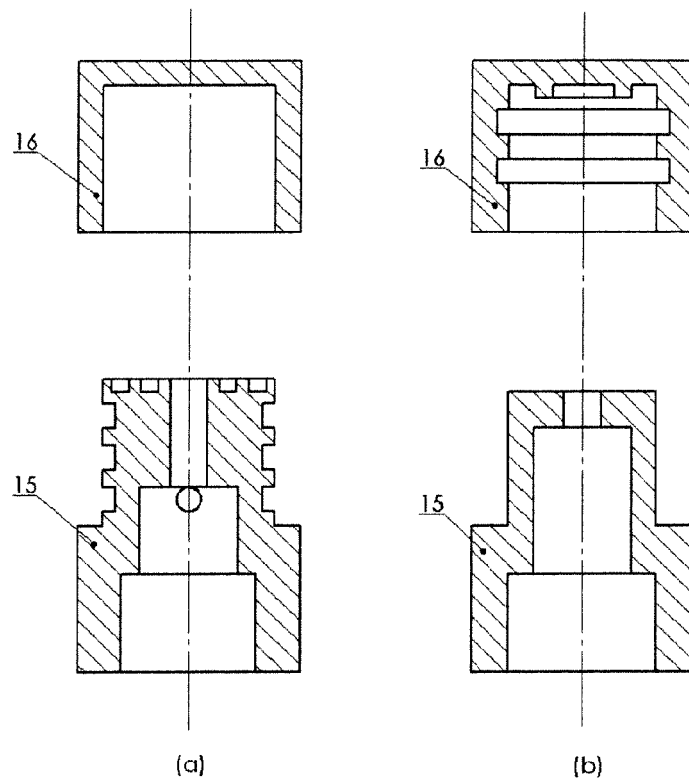


Fig.5. Example of piston parts prepared for final manufacturing process: (a) machining of cooling system into inner part, and (b) machining of cooling system into outer part.

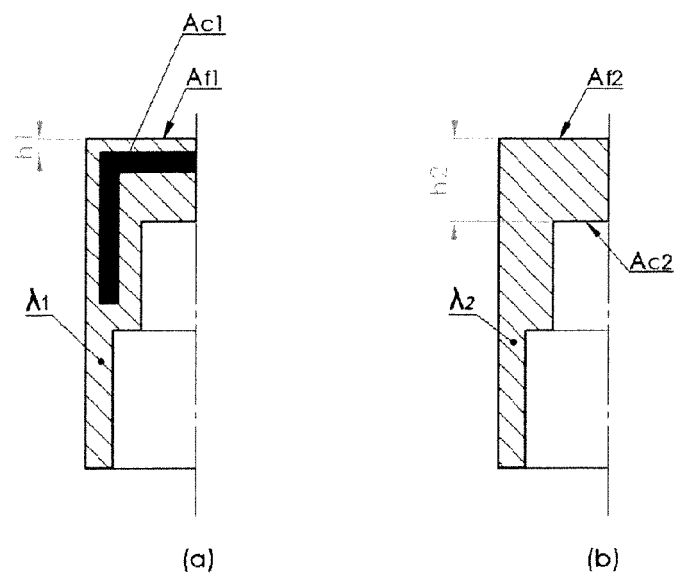


Fig.6. Schematic of two cooling extremes: (a) ICS piston with maximum cooling efficiency, (b) standard-type piston.

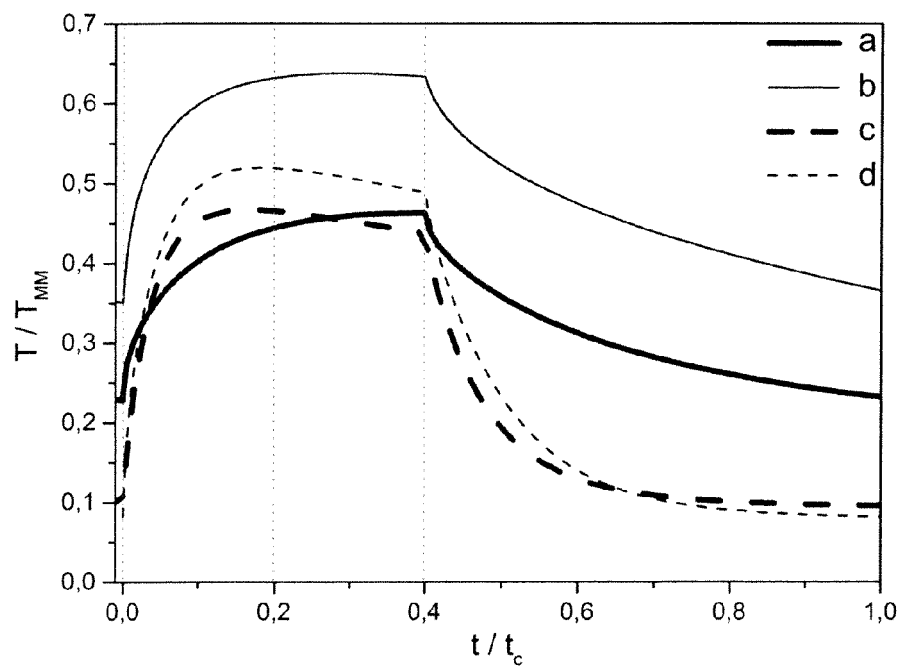


Fig.7. Plot demonstrating results of cooling optimization: (a) standard-type piston made of Cu alloy, (b) standard-type piston made of steel, (c) ICS piston with moderate Ac and piston-front made of Cu alloy, (d) ICS piston with moderate Ac and piston-front made of steel.



EUROPEAN SEARCH REPORT

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