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(54) **Piston for cold-chamber die-casting systems**

(57) Invention relates to die-casting piston comprising a piston body and a piston head specially designed for improved cooling effectiveness. The piston is pro-

posed as technically-enhanced cost-effective alternative to standard-type copper-alloy pistons generally utilized by casting industry.

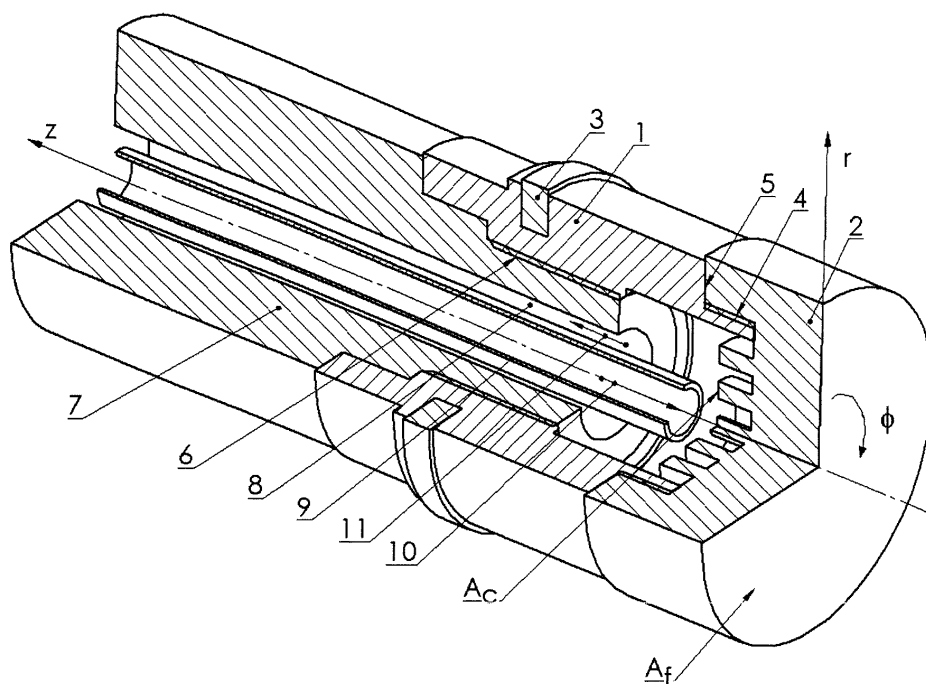


Fig.1. Schematic of the novel die-casting piston with improved cooling effectiveness and cost effectiveness.

Description

[0001] Significance of the present invention is in engineering simplicity that provides basis for overall cost reduction of the piston compared to the standard-type piston, while offering full flexibility for selection of required cooling effectiveness, also significantly higher compared to that of the standard-type piston, as well as maintaining or improving possibilities for its refurbishment.

DESCRIPTION

Background and Summary

[0002] A die 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.

[0003] In cold-chamber die-casting molten metal is poured into a shot sleeve and from there pushed by a 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.

[0004] 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.

[0005] 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 the 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 its 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.

[0006] 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.

[0007] 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 surface and the piston inner surface, the corresponding distance, and coefficient of thermal conductivity (CTC) of the piston material, and (iii) difference in temperature between the piston inner surface and CF, surface area of the piston inner surface, and the corresponding heat transfer coefficient (CHT).

[0008] Cooling effectiveness of the piston can be improved by finding new solutions in the piston design primarily influenced by the following independent parameters: (i) surface area of the piston inner surface, (ii) thickness of the piston head, (iii) CTC, and (iv) CHT. CTC directly depends on selection of the piston-head material, whereas CHT depends on surface quality of the piston inner surface. The other two parameters, surface area of the piston inner surface, and thickness of the piston-head, are directly influenced by the piston design. Consequently, cooling effectiveness of the piston is increased by making the piston inner surface of maximum possible surface area, and make the piston head out of material with high thermal conductivity.

[0009] 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.

[0010] 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 2b). Copper-based alloys are used due to both their high thermal conductivity providing good transfer of heat energy from MM to CF, good sliding and sufficient sealing between the piston and the shot sleeve wall without using additional sealing rings. Such pistons are relatively expensive due to high cost of copper-based alloys utilized. Their cost effectiveness is usually improved by

simple and low-cost refurbishment performed. After their surface in contact with the shot sleeve wears out they are either turned to a lower diameter or welded and turned to the original diameter. Such refurbishment can be performed several times depending on the piston design. Standard-type pistons are used for low-series casting production, for pistons of smaller diameter, or generally for less demanding production.

[0011] Numerous technical solutions are applied to improvement of casting pistons. These primarily focus on improvement of the piston cooling or their thermal regulation, sealing, and possibility to prolong their in-service life by providing replacement parts. Such pistons are generally complex multi-part pistons used for higher series production, bigger piston diameters, or generally for high demanding production.

[0012] Nevertheless, industry shall continue using standard-type pistons for basic production and small series production. This invention is mainly related to improvement of cooling effectiveness of the standard-type piston as well as its cost effectiveness by:

- implementation of innovative technical solutions that substantially improve cooling effectiveness of the piston head,
- design optimization of the piston providing possibility to utilize lower-cost materials, while maintaining the improved cooling effectiveness and refurbishment flexibility compared to the standard-type piston.

[0013] The invention described in detail in the following text provides solution to above defined provisions. Figure 1 to 4 show the novel piston design and explain the invention.

Brief description of drawings

[0014]

- Fig.1. Schematic of the novel die-casting piston with improved cooling effectiveness and cost effectiveness.
- Fig.2. Comparison between: (a) the novel piston subject to this innovation, and (2) the standard-type piston.
- Fig.3. T-t plot demonstrating improved cooling effectiveness of the novel piston: (a) standard-type piston made of steel, (b) standard-type piston made of copper-based alloy, (c) novel die-casting piston having A_c/A_f equal to that of standard-type piston (in both cases $A_c/A_f = 0,3$), (d) novel die-casting piston with $A_c/A_f = 1,4$.
- Fig.4. Dimensions of the piston critical for refurbishment.

Detailed description

[0015] Figure 1 reveals the novel die-casting piston and shot rod assembly showing the piston body (1), the piston head (2), and an additional guiding and/or sealing ring (3). Surface area of the piston head in contact with molten metal (MM) is indicated by A_f , whereas surface area of the piston head inner wall in contact with coolant is indicated by A_c . The piston body and the piston head can be fastened together so that disassembly or replacement of the piston head is permitted, including but not limited to a screw-thread fixture (4), or they can be permanently bonded. The claimed invention is not limiting the type of this fixture. However, it must be engineered with safety elements appropriate for the application, and must assure absolute sealing between the piston body and the piston head (5). The piston and shot rod assembly (6) shown in Figure 1 is generally a well-known setup widely used in casting industry.

[0016] The shot rod (7) has an internal passage or central hole (8) used to transfer cooling fluid (CF) to and from the piston. CF transfer can be accomplished in different ways. One example is installation of two separate tubes built into this central passage, one for CF inflow to the piston and the other for CF outflow. Figure 1 shows a widely used system of a single tube (9) built-in into the central passage. This central tube is of smaller diameter than the central passage and used for CF inflow (10), whereas the passage between the shot-rod inner wall and the central tube serves for CF outflow (11). CF enters the piston through the inflow tube, flows over the piston-front inner-surface, and flows out via the central tube passage.

[0017] The invention relates particularly to improvement of the piston cooling effectiveness, while maintaining refurbishment advantages compared the standard-type piston and focusing on the piston overall cost-effectiveness. Figure 2 is a schematic showing comparison between the novel die-casting piston (Fig 2a) and the standard-type piston (Fig.2b). Separate fabrication of the piston head (2), which is attached to the piston body (1), either permanently or with possibility to disassemble the two parts, represents an important advantage of the presented setup. Namely, surface area A_c , critical to transfer of heat energy between the piston and CF, can be made significantly larger than that of the standard-type piston, A_c^s , improving the piston cooling effectiveness. The piston head has two functions in this case: (i) provides sliding and sealing against the shot sleeve wall in the same way as standard-type piston, and (ii) transfers heat energy between MM and CF.

[0018] The proposed setup consents the following advantages:

- the piston cooling effectiveness can be significantly improved compared to that of the standard-type piston by increasing the surface area of piston contact with CF ($A_c > A_c^s$), which can simply be made by

machining a specific geometry surface to inner side of the piston head. This can be made before assembling the piston body and the piston head, which is accessible for such machining;

- possibility to select different materials for the piston body and the piston head. A copper-based alloy same as in the standard-type piston can be used for the piston head, whereas the piston body can be made of a low-alloy steel. Considerable savings can be attained in the piston manufacturing this way, especially in bigger diameter pistons.
- The piston can be refurbished either by replacement of the piston head or it can be refurbished using the same method as the one utilized for standard-type pistons; this is by turning to a smaller diameter, or by welding and turning to the original diameter;

[0019] Cooling effectiveness of the piston depends on materials utilized and surface-area of the piston inner surface in contact with coolant, A_c . Larger surface area A_c in the piston subject to this invention is made by machining a specific geometry surface to inner side of the piston head. This is shown in Figure 2(a) as ribs in shape of concentric circles. The ribs can be made of any feasible shape and section geometry. The rib height, h_r , is at its maximum at $h_{r\max} l_1 - h_1$, in case the piston head is machined from a disk diameter D and uniform thickness l_1 . The ribs also assist mechanical resistance of the piston head. They are in direct contact with CF and are colder (at about the CF temperature) compared to the rest of piston head, and have therefore higher strength. This phenomenon permits either: (i) reduction of h_1 min, while maintaining d_c , or (ii) increase of d_c , while maintaining h_1 min. The later is shown in Fig.4 as a further increase in A_c for this type of piston.

[0020] For selected material of the piston head, the cooling effectiveness may also be expressed as a function of A_c/A_f . This way a direct comparison of cooling effectiveness related to pistons of different design and dimensions is allowed. For standard-type pistons the ratio equals 0,2 to 0,4 for smaller to bigger diameter pistons, respectively. The piston subject to this invention improves this ratio by up to a factor of 5, which means A_c/A_f can reach up to 1,0 for smaller diameter pistons, and A_c/A_f is up to 1,5 for bigger diameter pistons.

[0021] Figure 3 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) the standard-type piston made of steel, (b) the standard-type piston made of copper-based alloy, (c) the novel die-casting piston having A_c/A_f equal to that of the standard-type piston (in both cases $A_c/A_f = 0,3$), and (d) the novel die-casting piston with $A_c/A_f = 1,4$. For the purpose of this study the novel die-casting piston is made of a low-alloy steel and a copper-based alloy for the piston body and

the piston head, respectively. Results show that the standard-type piston made entirely of steel is least effective in transferring heat from MM to CF (see curve a). Temperature underneath the front surface of such piston is higher throughout the cycle compared to other pistons. The standard-type piston made entirely of a copper-based alloy has lower temperature than the novel piston of the same geometry (see curve b and c). This is because the copper-based standard-type piston transfers the heat from A_f to cylindrical part of the piston body and from there to CF better than the novel piston with the body made of steel. This phenomenon can be interpreted by assumption that the piston inner surface, A_c , in function to transfer the heat to CF is in this case represented by both the inner surface of the piston front and a part of the inner surface of the piston cylindrical side wall, all together denoted as A_c^s . However, results show that design of the piston subject to this invention has, despite the phenomenon explained, flexibility to manufacture considerably larger A_c compared to that of the standard-type piston, A_c^s . Therefore, such piston can be designed with considerably higher cooling effectiveness with important influence to reduction of casting cycle time compared to the standard-type piston (see curve d). Region between curve c and d in figure 3 demonstrates the range in which cooling effectiveness of the piston subject to this invention can be chosen, essentially with no extra manufacturing costs.

[0022] Figure 4 shows the piston dimensions critical for refurbishment. There are three possible methods for refurbishment of this piston: (i) replacement of the piston head as critical part subjected to wear, erosion, and thermal fatigue or other possible failure mechanisms, (ii) turning the piston to smaller diameter, and (iii) turning and welding the piston to original diameter. The piston front-wall thickness, $h_{1\min}$, is determined by material resistance to thermal and mechanical loading in the pressurization phase of casting cycle. The piston front-wall can be made thicker, h_1 , which accommodates a desired number of piston refurbishments, but reduces its cooling effectiveness. In case the piston turning and diameter reduction is selected as refurbishment method, both thickness of the second ring and distance from the piston surface to position of the fixture between the piston head and the piston body, $h_{2\max}$, are selected based on desired reduction of the piston diameter. In this case the piston diameter can be reduced from its initial diameter, D , to a minimum possible diameter, $D_{\min}$.

[0023] It is important to note that the piston diameter reduction for refurbishment affects, in addition to casting machine parameters, also the piston cooling effectiveness by influencing the A_c/A_f ratio. Turning and welding to the original diameter or replacement of the piston head is therefore preferred refurbishment practice.

[0024] The piston head which is in contact with the shot-sleeve wall over its length l_1 , provides sliding and sealing properties. To assure correct linear movement of the piston in the shot sleeve, a second ring (3) at a

distance l_2 from the piston head, or plurality of rings, may be added. This reduces wear of the piston head and prolongs its in-service life. The width of the second ring, l_3 , or plurality of rings, must be sufficient to provide good piston guidance. The rings may be manufactured by welding of a copper-based alloy into a groove made to the piston body. The present invention is not limiting the manufacturing technology of the rings nor the materials selected.

[0025] Significance of the present invention is in engineering simplicity that provides basis for overall cost reduction of the piston compared to the standard-type piston, while offering full flexibility for selection of required cooling effectiveness, also significantly higher compared to that of the standard-type piston, as well as maintaining or improving possibilities for its refurbishment.

Claims

1. A piston mounted on a shot rod and moving inside a shot sleeve of a die-casting press for pushing molten metal from shot sleeve into a die, comprising a piston body and a piston head, wherein said piston body (1) has an outer cylindrical surface facing the shot sleeve, an inner cylindrical surface in contact with cooling fluid and with the shot rod, a mechanism, including but not limited to thread, for fastening said piston body to the shot rod, and a mechanism (4), including but not limited to thread, for fixing a piston head to said piston body; wherein said piston head (2) has an outer cylindrical surface in contact over its height (l_1) with the shot sleeve, a front surface (A_f) in contact with molten metal, a back surface (5) in contact with said piston body, a mechanism, including but not limited to thread, for fixing said piston head to said piston body, and, essential for this invention, an inner surface (A_c) in contact with cooling fluid; wherein said piston head is fastened to said piston body; wherein said piston head inner-surface (A_c) is a circular plane with addition of particular geometric elements, including but not limited to ribs of a rectangular cross-section, in the form of one or plurality of concentric circles, or in the form of a spiral;
2. The piston as recited in claim 1, wherein said piston head inner-surface is either:
 - a circular plane of diameter (d_c) smaller, equal, or bigger compared to diameter of thread (6) for fastening said piston-body to the shot rod;
 - an arbitrary three-dimensional surface constructed over said circular plane and limited by height (l_1) of said piston-head;
 - an arbitrary three-dimensional surface constructed over said circular plane with no limita-

tion of its height.

3. The piston as recited in claim 2, wherein diameter of said circular plane and/or design of said three-dimensional surface are defined by required piston cooling effectiveness, which depends on the ratio of surface area of said piston head inner-surface (A_c) to surface area of said front surface (A_f).
4. The piston as recited in any preceding claim, wherein said piston head is attached to a shot rod; wherein cooling fluid entering the piston through the passage in said shot rod comes to direct contact with said piston head inner-surface (A_c); wherein mass flow of the cooling fluid is essential to determine the shape of said piston head inner surface which defines piston cooling effectiveness; wherein cooling fluid after being in contact with said piston head inner surface flows back to the passage in said shot rod.
5. The piston as recited in any preceding claim, wherein said piston head is attached to said piston body by a fastener structurally adequate for this application that seals the contact between said piston head and said piston body and permits disassembly of said piston head from said piston body, including but not limited to screw-thread or bayonet-type fastener.
6. The piston as recited in claims 1 to 4, wherein said piston head is permanently fastened to said piston body.
7. The piston as recited in claims 1 to 5, wherein said fastener is made such that reduction of piston diameter (D) to smaller diameter (D_{min}) does not affect said fastener integrity or compromise its sealing function.
8. The piston as recited in any preceding claim, wherein said piston head is made of material different than said piston body.
9. The piston as recited in any preceding claim, wherein the piston has a guiding ring (3), which is a cylindrical element fastened to said piston body or to said piston head outer cylindrical surface, or is fabricated by, including but not limited to, welding a predisposed groove in said piston body outer cylindrical surface.
10. The piston as recited in any preceding claim, wherein plurality of said guiding rings are positioned at said piston body or at said piston head.

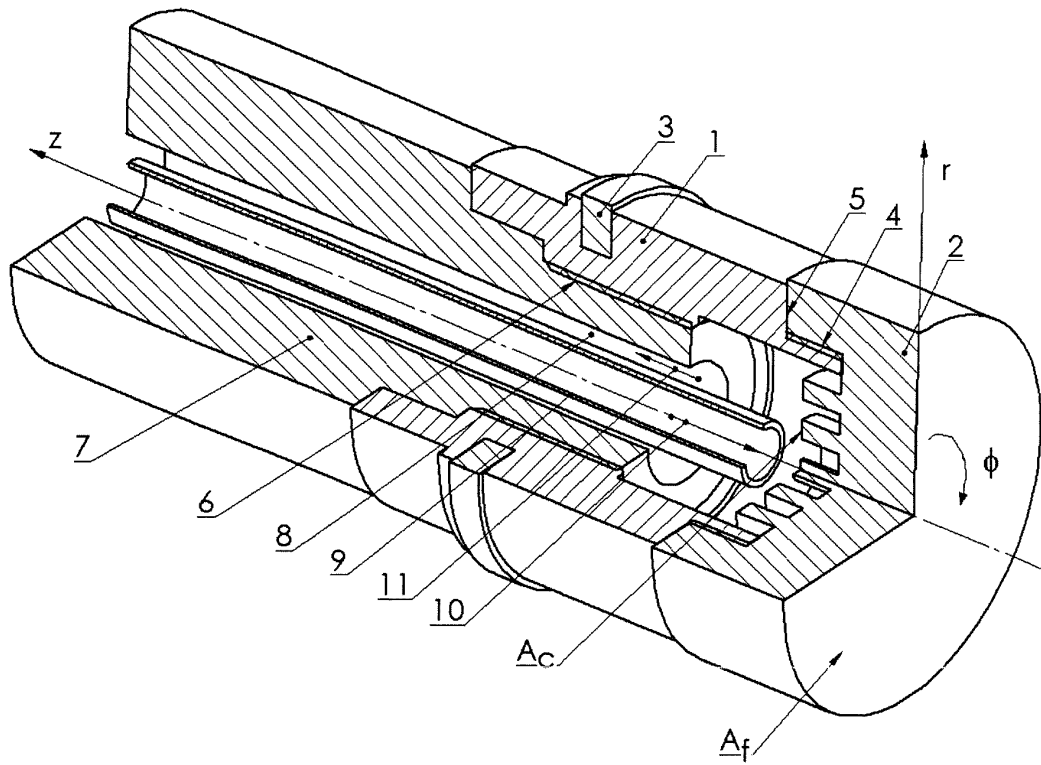


Fig.1. Schematic of the novel die-casting piston with improved cooling effectiveness and cost effectiveness.

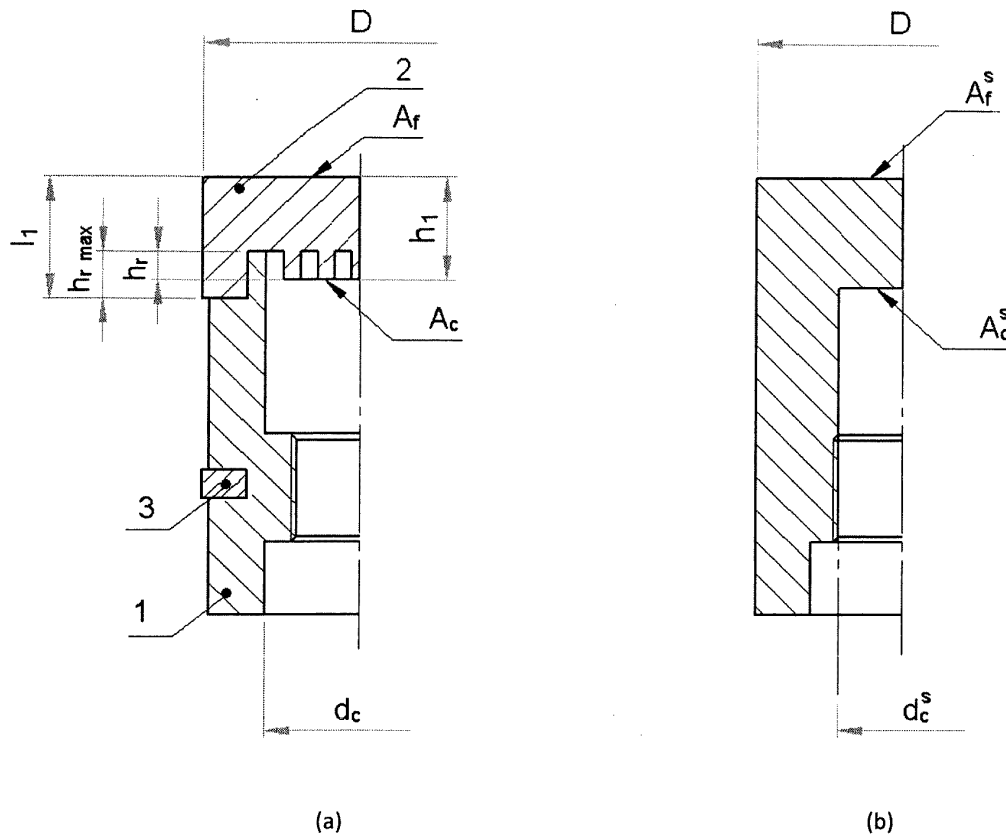


Fig.2. Comparison between: (a) the novel piston subject to this innovation, and (2) the standard-type piston.

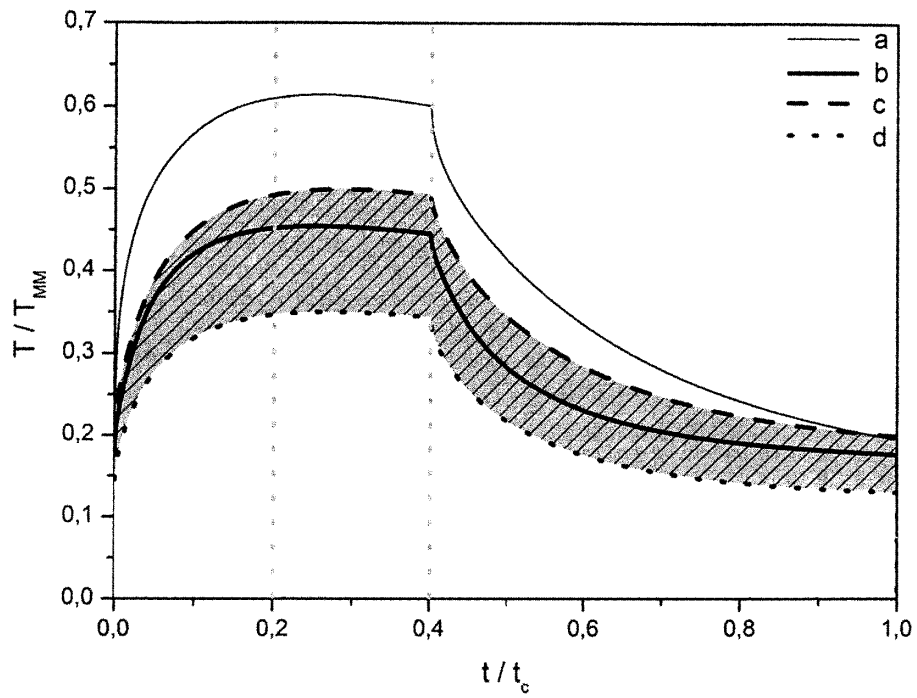


Fig.3. T-t plot demonstrating improved cooling effectiveness of the novel piston: (a) standard-type piston made of steel, (b) standard-type piston made of copper-based alloy, (c) novel die-casting piston having A_c/A_f equal to that of standard-type piston (in both cases $A_c/A_f = 0.3$), (d) novel die-casting piston with $A_c/A_f = 1.4$.

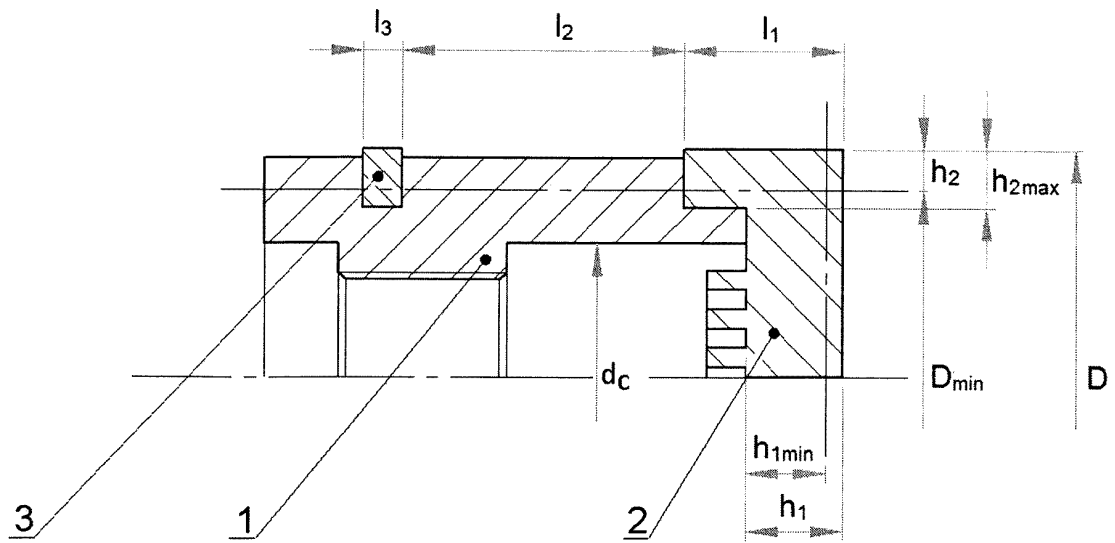


Fig.4. Dimensions of the piston critical for refurbishment.