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NEW MOULD WITH COMBINED – INDIRECT AND DIRECT COOLING, FOR VERTICAL UPWARDS CONTINUOUS CASTING OF ALUMINIUM WIRES

NOVI KALUP SA KOMBINOVANIM - INDIREKTNIM I DIREKTNIM HLAĐENJEM, ZA KONTINUALNO VERTIKALNO LIVENJE-NAGORE ALUMINIJUMSKIH ŽICA

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Keywords
- upwards continuous casting
- mould
- aluminium wires
- drawing mechanism

Abstract

A trend in higher demand of aluminium wires for industrial purposes has been observed in recent years. The most popular, basic methods for aluminium wire production include continuous or semi-continuous casting, extrusion and drawing.

The investigated method involves drawing of the crystallized metal in a vertical direction upwards toward the liquid metal in the melting furnace. This method has been so far applied only for continuous casting of copper and copper alloy wires. The main advantage of this casting method is the simultaneous operation of several moulds (crystallizers) immersed in liquid metal and the possibility to stop easily each of them while the rest of the moulds continue their function. Another advantage of the upwards continuous casting is the absence of a tundish.

The pilot equipment for vertical upwards continuous casting of aluminium wires is designed and produced. It consists of a copper water-cooled mould (crystallizer) up to 14 mm in diameter and a hydraulically driven drawing mechanism.

Because of the high thermal capacity of aluminium, the achieved maximum casting speed 280 mm/min is unsatisfactory. A new mould, with combined indirect and direct cooling for vertical upwards continuous casting of aluminium wires was designed and produced.

The casting speed of aluminium wires (Ø14 mm) was increased to 1000 mm/min, using the new mould.

Ključne reči
- kontinualno livenje nagore
- kalup
- aluminijumske žice
- mehanizam za izvlačenje

Izvod

U poslednjih nekoliko godina posmatran je postojeći trend sve većih zahteva u primeni aluminijumskih žica za industrijske svrhe. Najpopularnije, osnovne metode u proizvodnji aluminijumskih žica obuhvataju kontinualno ili polukontinualno livenje, istiskivanje i izvlačenje.

Razmatrani metod podrazumeva izvlačenje očvrslog metala u vertikalnom pravcu nagore, ka tečnom metalu u peći za livenje. Ovaj metod je do sada primenjen samo za kontinualno livenje žica od bakra i legure bakra. Osnovna prednost ovog metoda livenja je istovremena operacija u nekoliko kalupa (kristalizatora) potopljenih u tečni metal, kao i mogućnost lakog prekidanja operacije kod bilo kojeg kalupa, dok se kod ostalih kalupa operacija ne prekida. Druga prednost kontinualnog livenja aluminijuma nagore je što je posuda za ulivanje rastopa nepotrebna.

Projektovana je i proizvedena pilot oprema za vertikalno kontinualno livenje aluminijumskih žica nagore. Sastoji se iz bakarnog vodom hlađenog kalupa (kristalizator), prečnika do 14 mm, i hidrauličnog mehanizma za izvlačenje.

Zbog visokog toplotnog kapaciteta aluminijuma, dostignuta maksimalna brzina livenja od 280 mm/min je nezadovoljavajuća. Projektovan je i proizveden novi kalup sa kombinovanim indirektnim i direktnim hlađenjem za vertikalno kontinualno livenje aluminijumskih žica nagore.

Brzina livenja aluminijumskih žica (Ø14 mm) je povećana na 1000 mm/min, upotrebom novog kalupa.

INTRODUCTION

The upwards continuous casting of copper, brass and bronze finds increasingly wide application, /1–11/. Particularly good technical and economic results have been achieved by "RAUTOMEAD" Ltd, /5/.

In essence, the method (Fig. 1) consists in continuous drawing of profile (< Ø30 mm) through a graphite casting die placed inside a water-cooled copper mould immersed from the top to a definite depth in molten metal, /5/. The crystallized section is extracted from the mould by means of a drawing mechanism consisting of a roller system driven in a specific manner after which the profile is coiled.

The detailed patent search and in-depth analysis of literature showed that the above-described method has not been applied to continuous casting of aluminium and its alloys.

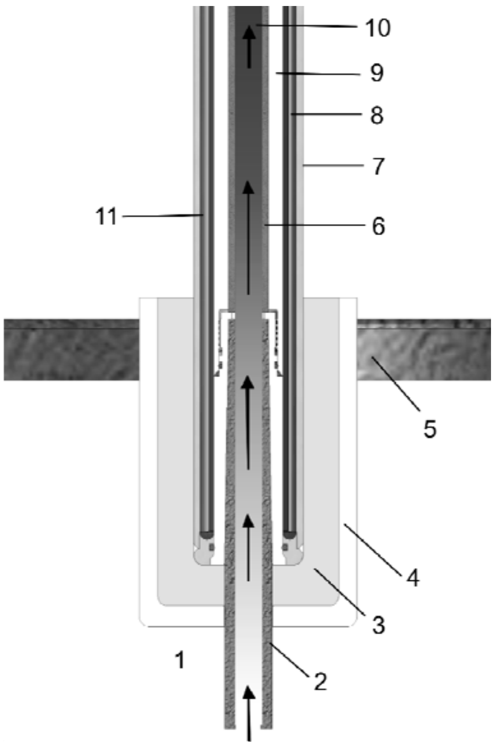


Figure 1. Scheme of upwards continuous casting of metals, /13/: 1-liquid metal; 2-graphite casting die; 3-heat insulating wadding; 4-graphite-fireclay cup; 5-furnace crucible; 6-graphite bushes; 7-external mould pipe; 8-intermediate pipe; 9-internal copper mould pipe; 10-cast metal profile;11-cooling water.

Slika 1. Šema kontinualnog livenja metala nagore, /13/: 1-tečni metal; 2-grafitni kalup za livenje; 3-ispuna toplotne izolacije; 4-grafitna-šamotna posuda; 5-jamasta peć; 6-grafitna podloga; 7-spoljašnji cevni kalup; 8-središnja cev; 9-unutrašnja bakarna kalupna cev; 10-profil izlivenog metala;11-rashladna voda.

In the work process, /13/, the basic possibility of efficient upwards continuous casting of aluminium and its alloys is ascertained. The main installation units – water-cooled mould (Fig. 2) and drawing mechanism (Fig. 3) were designed, manufactured, and put into operation.

Results from the initial experiments had confirmed the assumption that in comparison to the upwards continuous casting of copper and copper alloys, the application of the method for casting of aluminium and its alloys is characterised by considerably lower productivity.

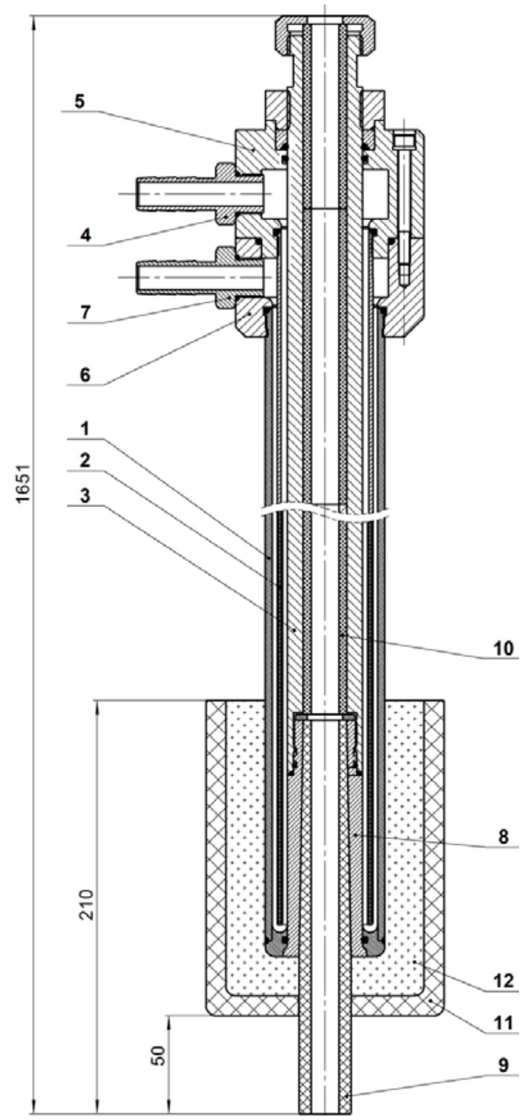
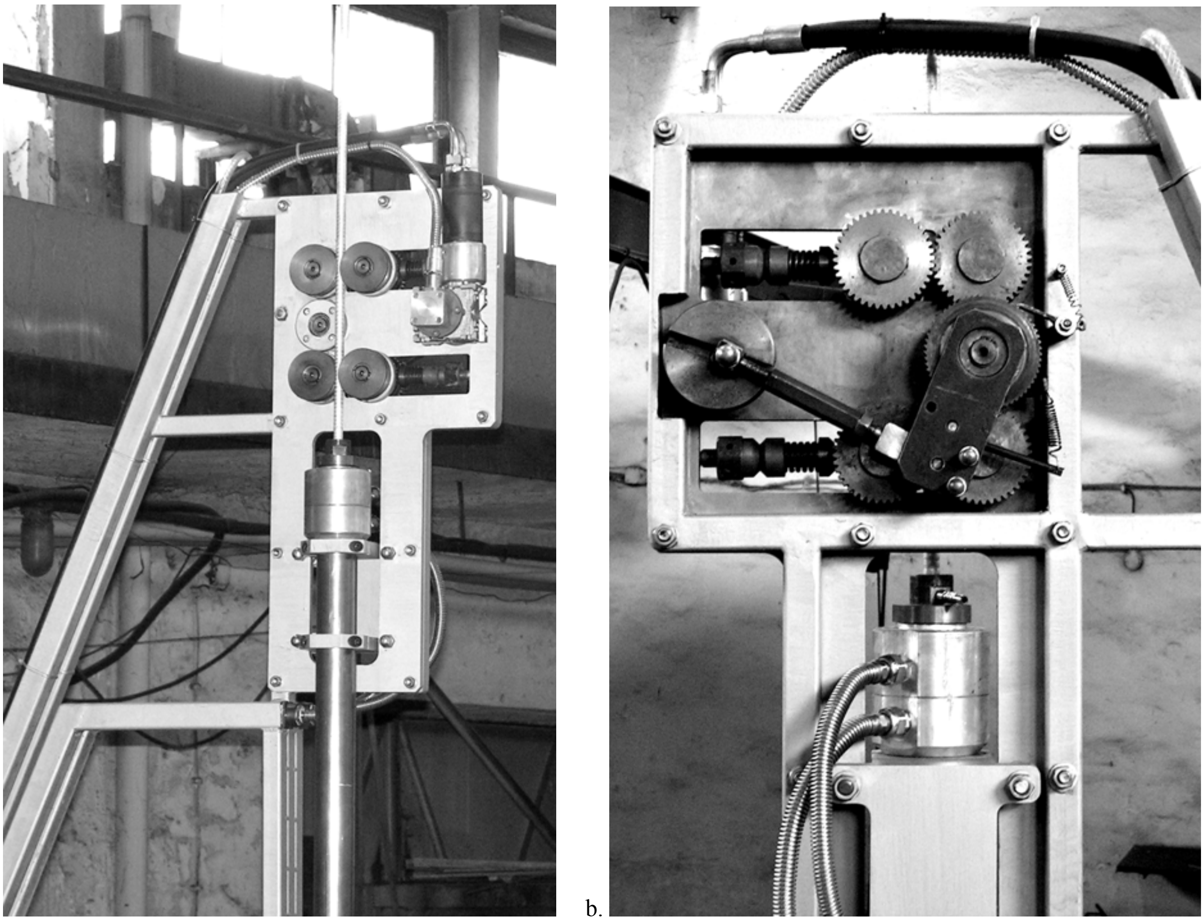


Figure 2. Water cooled mould for upwards continuous casting of metals, /13/: 1-external mould pipe; 2-intermediate pipe; 3-internal copper mould pipe; 4-orifice "in-water"; 5-upper flange; 6-down flange; 7-orifice "out-water"; 8-copper mould; 9–graphite casting die; 10-graphite bushes; 11-graphite-fireclay cup; 12-heat insulating wadding.

Slika 2. Vodeno hlađeni kalup za kontinualno livenje metala, /13/: 1-spoljašnja cev kalupa; 2-središnja cev; 3-unutrašnja bakarna cev kalupa; 4-dovod vode; 5-gornja prirubnica; 6-donja prirubnica; 7-odvod vode; 8-bakarni kalup; 9–grafitni kalup za livenje; 10-grafitna podloga; 11-grafitna-šamotna posuda; 12-ispuna toplotne izolacije.

While in the first case of copper casting, a casting speed of over 2000 mm/min was achieved (profile Ø14 mm, /1/), the casting speed of aluminium with the same dimensions had a maximum rate one order of magnitude lower, /13/.

The specific thermal capacity of aluminium at crystallization temperature is 900 J/kgK, /12/, i.e. significantly higher than that of copper (385 J/kgK). Having in mind that the latent heat of aluminium crystallization is also higher ($3.96 \cdot 10^5$ J/kg) compared to copper ($2.05 \cdot 10^5$ J/kg), one could expect significant differences in the technological parameters of the upwards continuous casting of copper and aluminium, as well as for their alloys.



a. b.

Figure 3. Installation for upwards continuous casting of aluminium wires, /13/: a) support structure with mould and drawing mechanism; b) moving eccentric with ratchet and gear mechanisms.
Slika 3. Instalacija kontinualnog livenja aluminijumskih žica nagore, /13/: a) konstrukcija nosača sa kalupom i mehanizmom za izvlačenje; b) pokretni ekscentar sa zapornim i prenosnim mehanizmima.

The obtained results, /13/, demonstrated that in order to improve significantly the productivity of the upwards continuous casting process, special measures should be applied for increasing the cooling intensity of the cast profile immediately downstream of the zone where the skin is detached from the wall of the graphite casting die. That necessitated significant additional modifications in the mould design related to the application of direct water cooling of the cast section.

Beside the specific, adverse thermo-physical parameters during the transition of aluminium from liquid into solid state of aggregation during the upwards casting, after a hard skin is formed in the crystallization zone, it shrinks and gets detached from the cooled wall of the graphite casting die. During the classical continuous casting process (from the top downwards), the metallostatic pressure of the liquid metal in the tundish considerably delays that shrinking and detachment of the skin from the mould wall. Also, vice versa, in the case of upwards continuous casting, the crystallized metal skin is subjected to significant tensile stresses by the drawing mechanism, due to which the section in the zone of the thin skin and liquid core wears thinner. The cross section of the air gap increases. The amount of heat abstracted from the profile drastically decreases, the core remains liquid, and the skin – thin, with insufficient mechanical strength, and the profile breaks. In order to avoid the above-mentioned drawbacks of the classical method for upwards continuous casting, a new idea was adopted, to apply two-stage – indirect cooling followed by direct cooling of the cast profile. That idea was implemented by means of an ingenious design of a new type of mould, where cooling of the liquid metal in the graphite casting die installed tightly in the immersed part of the water-cooled copper mould is indirect, and the cast profile is subjected also to direct cooling.

According to the new solution, the extra direct cooling is performed using an aerosol mixture in the zone of metal crystallization located immediately after the top of the graphite casting die of the water-cooled mould. Thanks to the controlled flow rate, the liquid from the aerosol mixture evaporates from the surface of the metal profile before reaching the graphite casting die.

Serious additional modifications in the mould design are needed for implementation of the method described here above, involving application of additional direct cooling to the cast section.

DESIGN OF NEW MOULD FOR VERTICAL UPWARDS CONTINUOUS CASTING OF METALS AND ALLOYS WITH HIGH THERMAL CAPACITY

The mould for upwards continuous casting of metals and alloys with high thermal capacity presented in Figs. 4–13 consists of the following components: a water-cooled mould installed over a furnace unit and immersed up to a certain level in the molten metal (30) (Fig. 4), consisting of working head (1) (Figs. 4 and 5), support body (2) and collector (3), situated one above the other. The working head of the mould is mounted along the centre line of the graphite-fireclay cup (4) (Fig. 6), with a mounting hole at the bottom for the graphite casting die (5), through which the latter reaches the front of the graphite-fireclay cup (4).

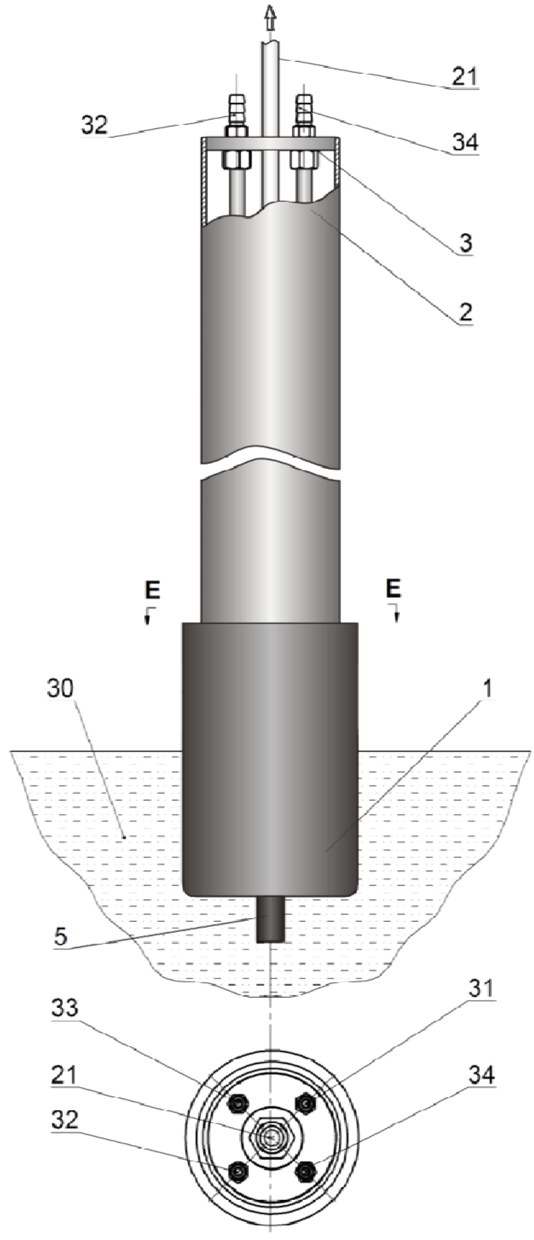


Figure 4. Scheme of new mould for upwards continuous casting of metals and alloys with high thermal capacity: 1-working head (graphite-fireclay cup); 2-support body; 3-collector; 5-graphite casting die; 21-cast aluminium wire; 30-liquid aluminium; 31-orifice "К-in-water"; 32-orifice "К-out water"; 33-orifice "К-liquid cooling agent"; 34-orifice "К-gas".

Slika. 4. Šema novog kalupa za kontinualno livenje nagore metala i legura sa velikim toplotnim kapacitetom: 1-radna glava (grafitna-šamotna posuda); 2-telo konstrukcije; 3-kolektor; 5-grafitni kalup za livenje; 21-livena aluminijumska žica; 30-tečni aluminijum; 31-dovod „К-voda“; 32-odvod „К-voda“; 33-dovod „К-tečni rashladni agens“; 34-dovod „К-gas“.

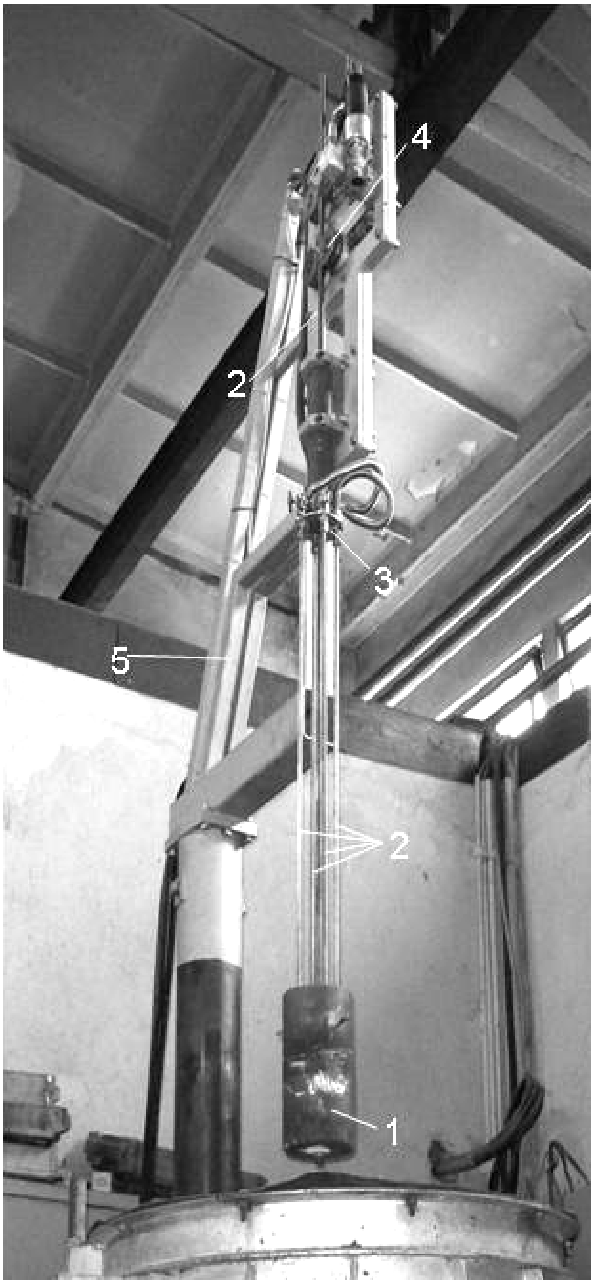
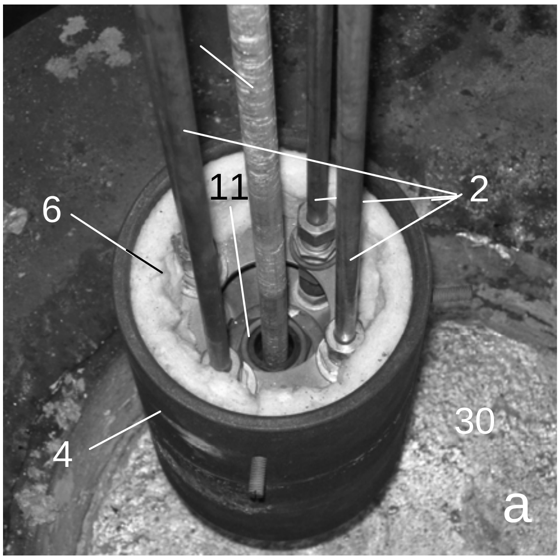


Figure. 5. Mould for upwards continuous casting of metals and drawing mechanism installed on support frame: 1-working head (graphite-fireclay cup) with graphite casting die; 2-supply pipes (the support body 2, Fig. 4, is not shown); 3-collector; 4-drawing mechanism; 5-support frame; 21-cast aluminium wire.

Slika. 5. Kalup za kontinualno livenje nagore metala i mehanizam za izvlačenje ugrađeni na nosećem ramu: 1-radna glava (grafitna-šamotna posuda) sa grafitnim kalupom za livenje; 2-dovodne cevi (telo konstrukcije-2, sl. 4, nije prikazano); 3-kolektor; 4- mehanizam za izvlačenje; 5-noseći ram; 21-livena aluminijumska žica.



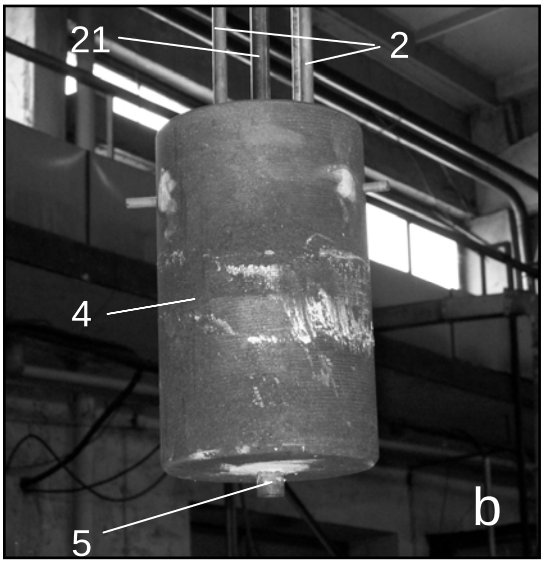


Figure 6. Working head of mould for upwards continuous casting of metals and alloys with high thermal capacity: a) plan view; b) bottom view; 2-supply pipes (support body 2, Fig. 4 is not shown); 4-graphite-fireclay cup; 6-heat insulating wadding; 5-graphite casting die; 11-copper mould; 21-cast aluminium wire Ø14 mm; 30-liquid aluminium.

Slika 6. Radna glava kalupa za kontinualno livenje nagore metala i legura sa velikim toplotnim kapacitetom: a) pogled odozgo; b) pogled sa strane; 2-dovodne cevi (telo konstrukcije, sl. 4, nije prikazano); 4-grafitna-šamotna posuda; 6-ispuna toplotne izolacije; 5-grafitni kalup za livenje; 11-bakarni kalup; 21-livena aluminijumska žica Ø14 mm; 30-tečni aluminijum.

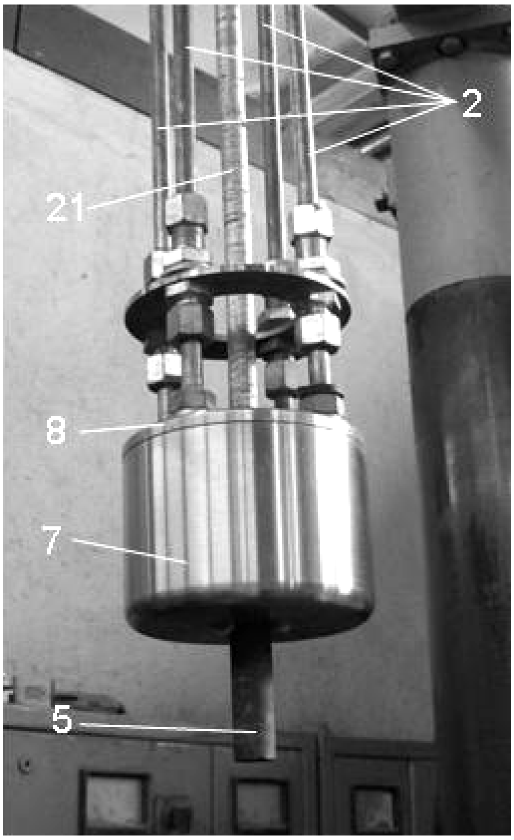


Figure 7. Working head of mould without graphite-fireclay cup and heat insulating wadding: 2-supply pipes; 5-graphite casting die; 7-cup with body; 8-cover; 21-cast aluminium wire.

Slika 7. Radna glava kalupa bez grafitne-šamotne posude i ispune toplotne izolacije: 2-dovodne cevi; 5-grafitni kalup za livenje; 7-posuda sa telom; 8-poklopac; 21-livena aluminijumska žica.

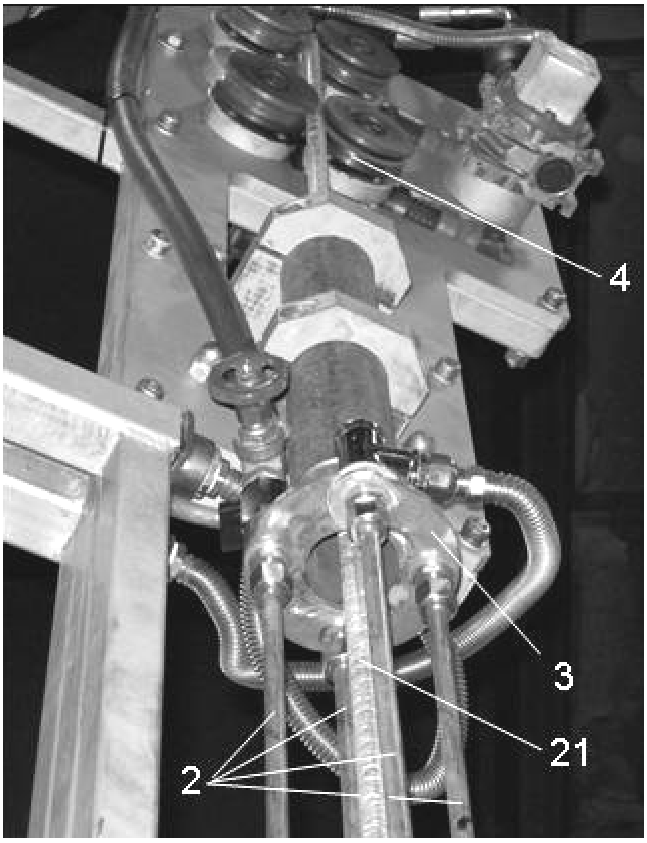


Figure 8. Collector of mould with drawing mechanism: 2-supply pipes; 3-collector; 4-drawing mechanism; 21-cast aluminium wire.

Slika 8. Kolektor kalupa sa mehanizmom za izvlačenje: 2-dovodne cevi; 3-kolektor; 4-mehanizam za izvlačenje; 21-livena aluminijumska žica.

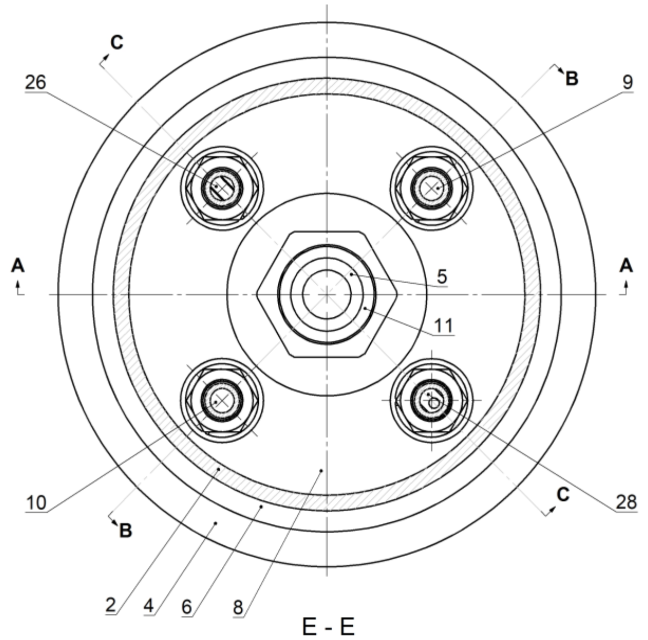


Figure 9. Mould for upwards continuous casting of metals and alloys with high thermal capacity (cross-section E-E from Fig. 4): 2-support body; 4-refractory protecting layer; 5-graphite casting die; 6-heat insulating wadding; 8-cover; 9-orifice “in-water”; 10-orifice “out-water”; 11-copper mould; 26-orifice “liquid cooling agent”; 28-orifice “gas”.

Slika 9. Kalup za kontinualno livenje nagore metala i legura sa velikim toplotnim kapacitetom (poprečni presek E-E sa sl. 4): 2-telo konstrukcije; 4-vatrostalni zaštitni sloj; 5-grafitni kalup za livenje; 6-ispuna toplotne izolacije; 8-poklopac; 9-dovod vode; 10-odvode vode; 11-bakarni kalup; 26-dovod „tečnog rashladnog agensa“; 28-dovod „gasa“.

The working head of the mould consists of a cup-wise body (7) (Figs. 7 and 10), closed by cover (8). The space between the cup-wise body (7) of the working head and graphite-fireclay cup (4) is filled with refractory heat insulating wadding (6). Cover (8) rests on orifice “K-in-water” (9) and orifice “K-out water” (10) (Fig. 11), the separating barrier (12), between two cooling water spaces – “in” (13) and “out” (14) (Fig. 11).

Along the axis of the working head, two zones of cooling are formed one above the other (Fig. 10): lower zone – for indirect cooling, consisting of a copper crystallizer (11) with graphite casting die (5) packed tightly inside it and upper zone – for direct cooling, by means of cooling nozzles (15) for spraying of an aerosol cooling agent.

The working head contains a gas space (20) (Fig. 10), hydraulically isolated from the water cooling system for indirect cooling of the mould. The space (20) is designed for feeding of the gas component of the aerosol cooling agent to the cooling nozzles (15). The conical sleeve (19), around the cast metal profile (21), accommodates four cooling nozzles (15), arranged at 90° towards each other and at 45° towards the axis of the working head and in the direction of casting of the metal profile (21) (Fig. 10). The cooling nozzles (15) are of the “tube inside tube” type.

The quantities and proportion of components of the aerosol cooling agent fed through the cooling nozzles (15) – liquid cooling agent and gaseous dispersing and cooling agent, can be adjusted precisely depending on the cast profile diameter and chemical composition of the metal, for achievement of maximum casting speed and desired structure.

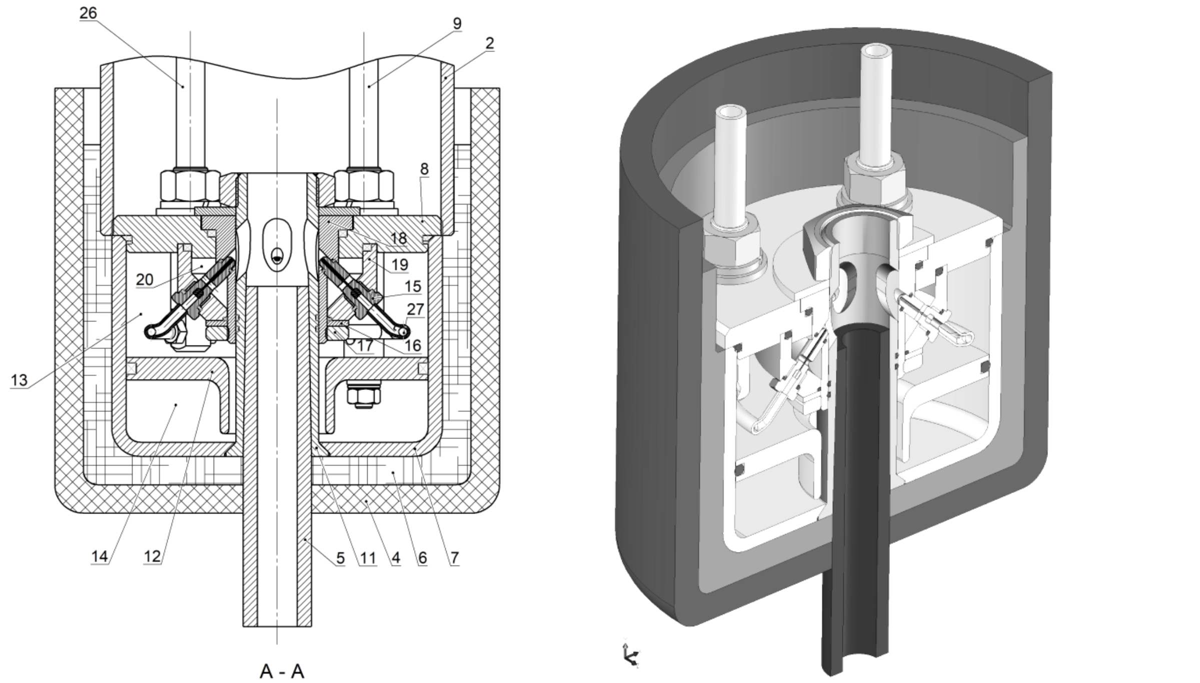


Figure 10. Working head of crystallizer for upwards continuous casting of metals and alloys with high latent melting heat (longwise section along A-A).

Slika 10. Radna glava kristalizatora za kontinualno livenje nagore metala i legura sa velikom latentnom toplotom topljenja (podužni presek duž A-A).

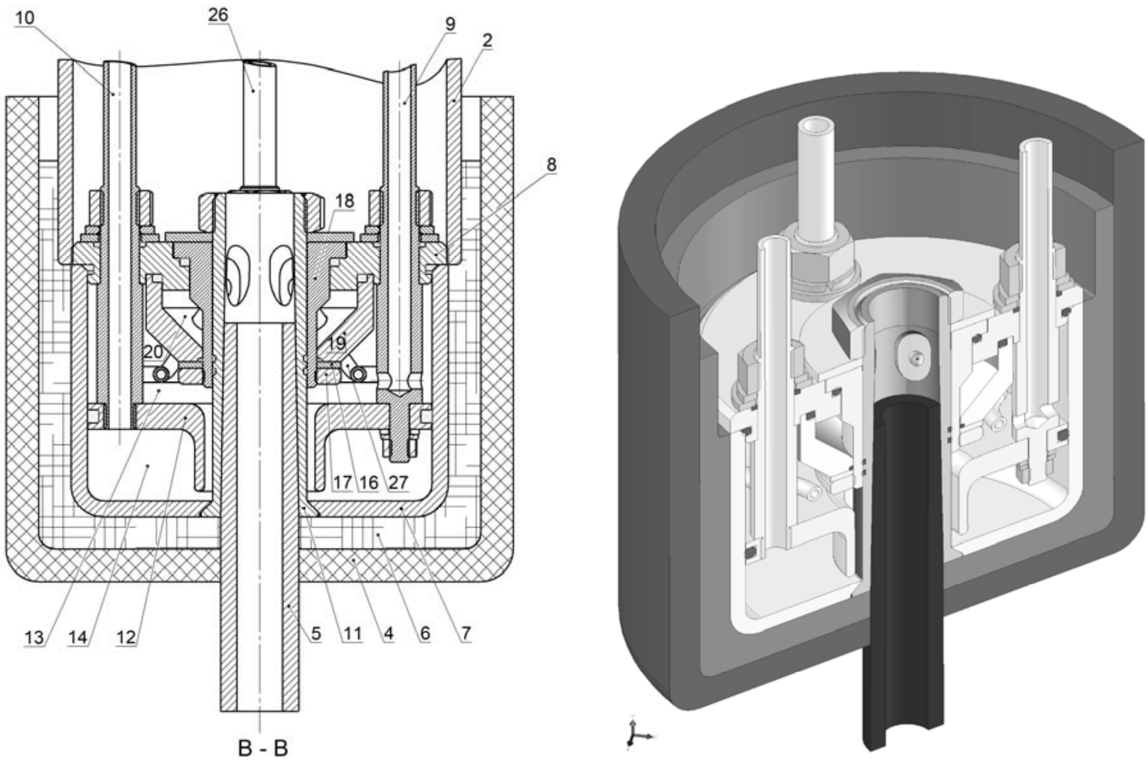


Figure 11. Working head of crystallizer for upwards continuous casting of metals and alloys with high latent melting heat (longwise section along B-B).
Slika 11. Radna glava kristalizatora za kontinualno livenje nagore metala i legura sa velikom latentnom toplotom topljenja (podužni presek duž A-A).

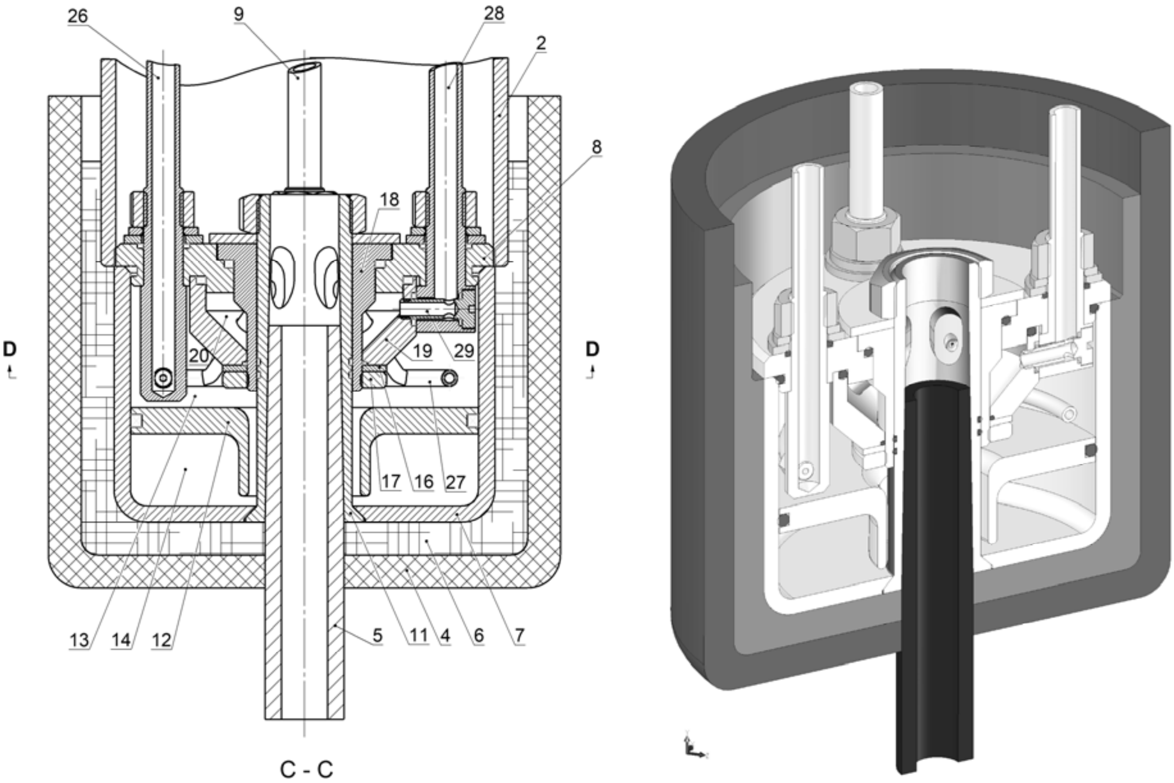


Figure 12. Working head of crystallizer for upwards continuous casting of metals and alloys with high latent melting heat (longwise section along C-C).
Slika 12. Radna glava kristalizatora za kontinualno livenje nagore metala i legura sa velikom latentnom toplotom topljenja (podužni presek duž C-C).

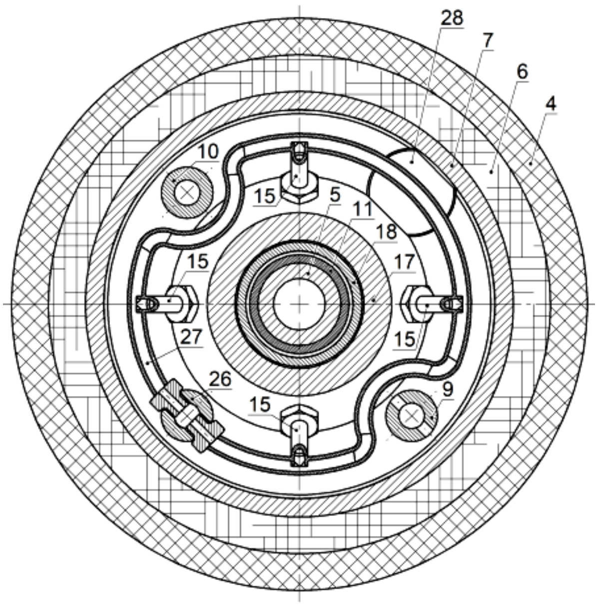


Figure 13. Working head of crystallizer for upwards continuous casting of metals and alloys with high latent melting heat (longwise section along D-D, from Fig. 12): 4-refractory protector (graphite fireclay); 5-graphite casting die; 6-refractory heat insulating wadding (mineral wool); 7-cup-wise body; 9-“in-water” orifice; 10-“out-water” orifice; 11-copper crystallizer; 15-cooling nozzle; 17-shaping nut; 18-cylinder shaping sleeve; 26-“liquid cooling agent” orifice; 27-annular collector; 28-“gas” orifice.

Slika 13. Radna glava kristalizatora za kontinualno livenje nagore metala i legura sa velikom latentnom toplotom topljenja (podužni presek duž D-D sa sl. 12): 4-vatrostalna zaštita (grafitni šamot); 5-grafitni kalup za livenje; 6-vatrostalna ispuna toplotne izolacije (mineralna vuna); 7-telo oblika čaše; 9-dovod vode; 10-odvod vode; 11-bakarni kristalizator; 15-rashladna mlaznica; 17-čaura za oblikovanje; 18-cilindrični rukavac za oblikovanje; 26-dovod tečnog rashladnog agensa; 27-prstenasti kolektor; 28-dovod gasa.

The support body (2) (Figs. 4 and 10) is a pipe fixed at one end to the cover (8) (Fig. 10) of working head (1) and at the other end – to the collector (3) (Fig. 4). Four connecting pipes pass through the pipe of the support body (2). They provide the connection between the “in-water” orifice (9), “out-water” orifice (10), “liquid cooling agent” orifice (26) and “gas” orifice (28) (Fig. 9) of the working head (1) (Fig. 7) and respective orifices “K-in-water” (31), “K-out-water” (32), “K-liquid cooling agent” (33) and “K-gas” (34) (Figs. 4 and 8), located in collector (3) of the installation.

The collector 3 (Figs. 4 and 8) is an annular flange where orifices “K-in-water” (31), “K-out-water” (32), “K-liquid cooling agent” (33) and “K-gas” (34) are mounted and to which the support body pipe (2) (Fig. 4) is fixed.

A series of experiments were carried out with the designed and manufactured crystallizer for casting of aluminium section Ø14 mm while the main technical parameters were maintained at the same level, varying only the flow rate of the liquid cooling agent – direct cooling water and the speed of drawing.

CONCLUSIONS

The designed and manufactured crystallizer with combined indirect and direct cooling performs its designed function by performing upwards continuous casting of aluminium with a productivity, commensurate to that of copper and copper alloy casting.

A rate of upwards continuous casting of aluminium section with Ø14 mm of 980 mm/min is achieved.

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