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Izzivi e-pogonskih komponent – rešitve v livarskih tehnologijah

Challenges E-Drive Components – Solutions in Casting Technology

0 Uvod

Avtomobilska industrija se zaradi pomanjkanja fosilnih goriv in zahtev političnega preoblikovanja energetske politike sooča z velikimi izzivi. Elektromobilnost postaja središče zanimanja in proizvajalce originalne opreme sili v premislek – ali naj tradicionalne pogonske sisteme pustijo za seboj in se podajo na pot usvajanja novih konceptov elektronskih pogonov?

Vse manjša količina virov in vse več pravnih predpisov vodita v porast obratovalnih stroškov za tradicionalne motorje z notranjim izgorevanjem. Dodatno vse večja količina emisij CO2 po vsem svetu in visoka okoljska osveščenost sprožata debato o skorajšnjem energetskem prehodu, kar se odraža v strogih okoljskih zakonodajah in državnih razvojnih programih. E-mobilnost in elektrifikacija vozil, ki jo spremlja, pridobivata vse več pozornosti.

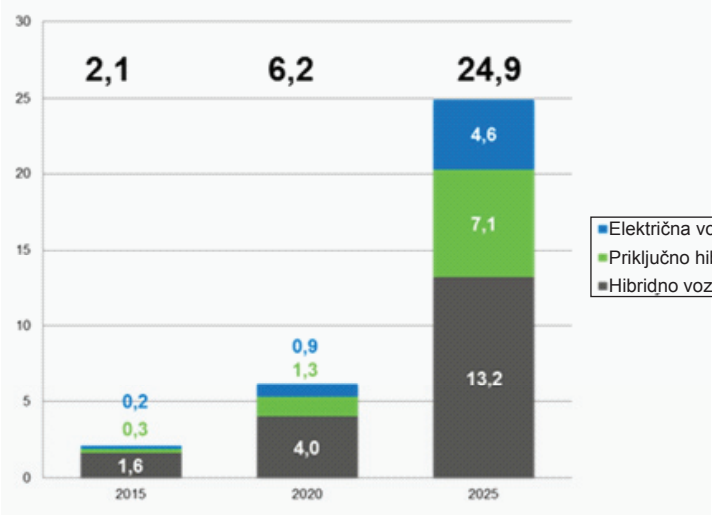
Velja splošno predvidevanje, da bodo električni pogoni srednje- ali dolgoročno zamenjali klasične motorje z notranjim izgorevanjem. Vendar pa do tega trenutka ne obstaja niti dogovor o natančnem datumu, kdaj naj bi se to zgodilo, niti o časovnem obdobju, kako dolgo bodo hibridne različice prisotne na tržišču. Napovedi trenutno predvidevajo pomemben porast tržnega deleža električnih in hibridnih vozil v naslednjih nekaj letih (gl. Sliko 1).

0 Introduction

Due to shortage of fossil fuels as well as to requirements of a political turnaround in energy policies the automotive industry is facing great challenges. E-mobility becomes the center of interest and forces the OEMs to rethink – leaving conventional powertrains behind and towards fostering new e-drive concepts.

The progressing shortage of resources as well as the increasing number of legal regulations leads to increasing operating costs for traditional combustion engines. Furthermore globally increasing CO2 emissions and a high environmental consciousness are driving the discussion about a nearby energy transition, expressed by strict environmental laws and governmental development programs. E-mobility and the accompanying electrification of vehicles continuously gain attention. It is commonly assumed that e-drives will replace traditional combustion engines on a mid- to long-term basis. Up to now, however, there is neither a consensus about the exact date of this incident nor about the period of time on how long hybrid solutions will stay in the market. Forecasts currently anticipate a significant increase of market shares for electric and hybrid vehicles over the next few years (see figure 1).

Due to the electrification of the powertrain the demand for die casting components for the realization of e-drives



Slika 1. Svetovna proizvodnja EV [v mio.][1]

Figure 1. Global EV Production [Mio.][1]

1 Roland Berger (2016): Global Automotive Supplier Study 2016

Zaradi elektrifikacije pogonskih sistemov se bo povpraševanje po kokilno litih komponentah za izvedbo elektronskih pogonov bistveno zvečalo. Velika sprememba v zgradbi vozil in vgrajene komponente bodo dolgotrajno vplivale na livarsko industrijo: številne tradicionalne kokilno lite komponente klasičnih pogonskih sistemov (motorni blok, glava motorja, ohišje menjalnika itn.) se bodo močno spremenile ali prenehale obstajati, zamenjale pa jih bodo nove lite komponente električnih pogonov. Hkrati bo potreba po lahkih komponentah, ki jo bo spremljal upad teže, v ospredje postavila pomen litih komponent, izdelanih iz neželeznih kovin, kot je aluminij.

Tukaj so izjemno pomembna ohišja električnih motorjev in akumulatorjev. To so izjemno kompleksni elementi zaradi vdelave različnih funkcij (npr. hladilnih kanalov). Prav tako se pričakuje, da se bodo dimenzije litih komponent zvečale, zvečala pa se bo tudi velikost serij, kar bo povzročila vse obsežnejša elektrifikacija. To predstavlja izjemen izziv zlasti za razvoj izdelkov in inženiring.

will increase significantly. The major change of the vehicle structure and of the built-in components will have a lasting effect on the foundry industry: A large number of conventional die casting components of the conventional powertrain (engine block, cylinder head, transmission housing, etc.) will change dramatically or drop completely and will be replaced by the new casting components of electrical drives. At the same time the necessity for lightweight solutions accompanied by the reduction of weight will push the significance of casting components made of non-ferrous metal like aluminum forward.

In this context the housings of e-motors and batteries are of great relevance.

These are highly complex elements due to the integration of additional functions (e.g. cooling channels). Furthermore it is expected that the dimensions of the casting components will expand and that the batch size will increase, both caused by the growing electrification. This represents a major challenge especially for product development and engineering.

Za izpolnitev zahtev glede teh novih litih komponent je nujna vpeljava novih postopkov in metod v verigo ustvarjanja vrednosti. To vpliva zlasti na same postopke ulivanja. Ekonomsko in tehnično primerna izbira postopka ulivanja je odvisna od kompleksnosti litja in zahtevanega števila proizvedenih delov. Zahteve glede lastnosti komponent, zlasti glede tesnjenja (neprepustnosti) in stabilnosti pri trku, so izjemno velike. Poleg tega je treba upoštevati tudi nadaljnje postopke na področjih mehanske obdelave, spajanja in sestavljanja. Zato so potrebne zmožnosti raznolike in zahtevajo celovito oceno celotne procesne verige. Proizvodni koraki, ki sledijo postopku ulivanja, bodo pridobili pomen v verigi ustvarjanja vrednosti.

Izzivi električno gnanih komponent, izdelanih iz aluminijastih litih delov, ki se pojavljajo pri potencialnih postopkih ulivanja, so podrobneje obravnavani v nadaljevanju.

1 Dvodelni obod ohišja električnega motorja

Danes je odstotek električnih motorjev na področju pogonskih sistemov v osebnih vozilih še vedno zelo majhen. Zato je tudi količina proizvedenih delov precej nizka. Trenutno ohišje električnega motorja družbe Nemak za vozilo BMW I3/I8 je zasnovano za proizvodnjo s kokilnim litjem. Kljub temu pa mora litje izpolniti visoke zahteve glede kakovosti. Da bi dosegli specifikacije glede trdnosti komponent in odpornosti proti koroziji, se uporablja livna zlitina AlSi z nizko vsebnostjo železa in bakra. Ohišje je hlajeno v tekočem mediju. Za izvedbo kompleksne konfiguracije, ki obdaja tudi sam motor, je ohišje zasnovano v dveh delih (gl. Sliko 2), da je primerno za proizvodnjo s kokilnim litjem, saj danes ni razpoložljivih ustreznih tehnologij za serijsko proizvodnjo,

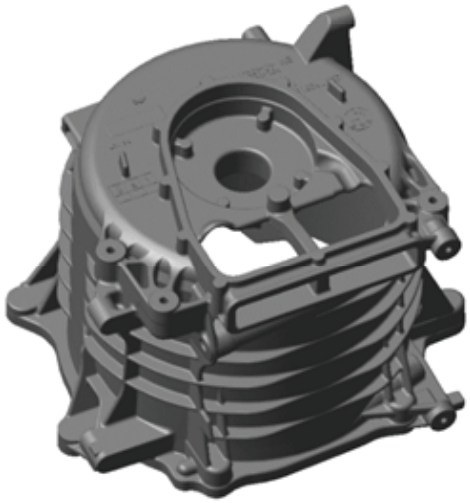
New processes and methods along the value-added chain are necessary to achieve the requirements for these new casting components. Mainly casting processes themselves are affected. Depending on the complexity of the die and the required number of pieces an economically and technically suitable casting process has to be selected. The required properties for the components, especially in the area of tightness (leak proof) and crash-stability, are very high. Apart from this, downstream processes in the area of mechanical treating, joining and assembly have to be considered. Therefore needed competences are diverse and require an overall evaluation of the entire process chain. The manufacturing steps which are downstream of the casting process will gain significance in the value-added chain.

The challenges of e-drive components made of aluminum-casting under consideration of potential casting processes are examined in more detail below.

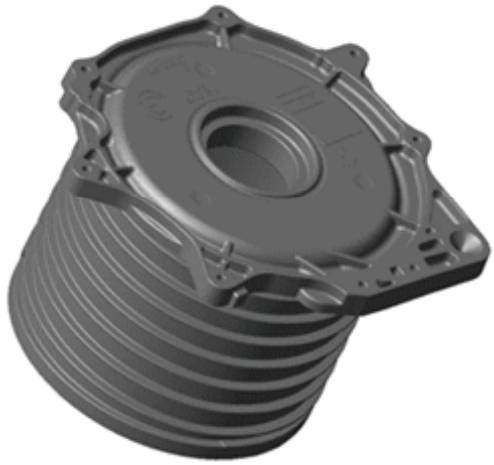
1 Two-part enclosure of e-motor housing

Today, the percentage of e-motors in the powertrain of passenger cars is still a single digit number. Correspondingly, the number of produced parts is rather low. Nemak's current e-motor housing for the BMW I3/I8 is designed for die casting production.

Nevertheless, the casting has to achieve high quality requirements. To achieve the specifications of the components strength and corrosion resistance an AlSi casting alloy with a low content of iron and copper is used. The housing is cooled through a liquid medium. To realize the complex configuration which also encloses the motor itself, the housing is produced as a two part design (see figure 2) in order to



Masa za litje 6,7 kg / Zunanje ohišje
Casting mass 6,7 kg / Outer housing



Masa za litje 4,5 kg / Notranje ohišje
Casting mass 4,5 kg / Inner housing

Slika 2. Dvodelni obod ohišja električnega motorja za vozilo BMW I3/I8

Figure 2. Two-part enclosure of e-motor housing for BMW I3/I8

ki omogoča izvedbo kompletov jeder z zajedami. Danes objavljene tehnike z jedri iz soli ne izpolnjujejo izjemnih zahtev v zvezi z notranjimi jedri za proizvodnjo ohišij električnih motorjev. Proizvodni postopek teh vrst ulitkov se izvaja s popolnoma opremljenim strojem za litje, ki izvaja tudi preizkuse puščanja. Za doseganje potrebnih lastnosti trdnosti so vsi deli ulivani pod vakuumom, nato pa še toplotno obdelani. Za zagotavljanje površine, ki skorajda ni porozna, je treba ohranjati ozko okno procesnih parametrov.

Poleg izpolnjevanja zahtev glede poroznosti je potrebno posebno pozornost nameniti tudi obdelavi delov po mehanski obdelavi s stroji zaradi majhnih dovoljenih odstopanj z vidika dimenzij.

2 Enodelni obod ohišja električnega motorja

Za prihodnja ohišja električnih motorjev je enodelno ohišje poleg standardnega,

enable a suitability for a production in die casting processes, since until today there is no technology available suitable for serial production which is able to realize core packages with undercuts. Nowadays published salt-core techniques don't meet the extraordinary requirements which internal cores for the production of e-motor housings require. The production process of these kinds of castings is realized with a fully equipped casting machine which also has the leakage test integrated. To reach the properties in concern of strength all parts are casted in vacuum and afterwards heat-treatment processed. To obtain a surface with almost no porosity a narrow window of process parameters must be kept.

Apart from compliance with the requirements of porosity, special attention should be payed to the treatment of the parts after the mechanical machining due to the narrow dimensional tolerances.

dvodelnega ohišja, ki se že uporablja pri serijski proizvodnji, realna možnost.

Visoka raven integracije, ki je potrebna tudi pri elektronskih pogonih najnovejše generacije, je zahtevna naloga, pri kateri so postopki kokilnega litja ključnega pomena. En primer je združitev elektronike pogona, električnega motorja in menjalnika v eno ohišje. Zaradi kompleksnosti zasnove, vključno s konfiguracijo hlajenja, sta na voljo dva procesa – nizkotlačno litje (LPDC) ali litje v pesek s peščenim jedrom (CPS® – Core Package System).

Na podlagi trenutnih konceptov je družba Nemak razvila ohišje električnega motorja, s katerim je prikazala, kaj je mogoče izvajati z nizkotlačnim litjem (LPDC) in tudi z litjem v pesek s peščenim jedrom (CPS®) (gl. Sliko 3). Za oceno potenciala obeh postopkov litja so osnovni zasnovi dodali tudi zahtevne spremembe lastnosti litja brez upoštevanja funkcije, npr. akumulacija mase v neugodnih položajih, ki se podaljša v priključke.

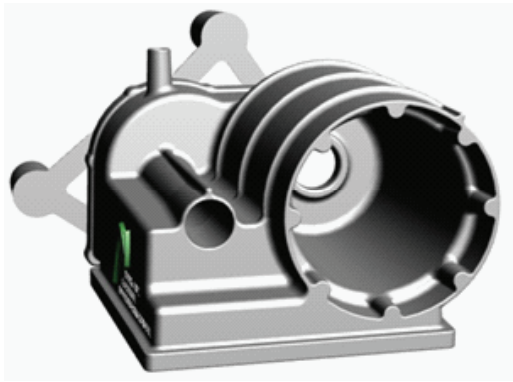
Demonstrator vključuje:

- prostor za stator,
- prostor za pogonsko elektroniko,

2 Single-part enclosure of e–motor housing

For future e-motors housings as single-piece housing apart from the common, two- part design, which is already applied in serial production, will be a realistic option. The high level of integration required also for e-drives of the latest generation is a challenging task which die casting processes are critical to cover. One example is the joining of power electronic, e-motor and transmission together in an integral housing. The complexity of the design including the cooling configuration makes Low Pressure Die Casting (LPDC) and the CPS® - Core Package Sand casting to the processes of choice.

Following current concepts, Nemak has developed an e-motor housing for demonstration reasons which can be casted in LPDC as well as in CPS® (see figure 3). In order to assess the potential of both casting processes additional challenging changes in casting properties in the basic design have been applied with no relevance to the function, e.g. mass accumulations in



Slika 3. Enodelni liti demonstrator ohišja, zasnovan za postopek nizkotlačnega litja (LPDC)

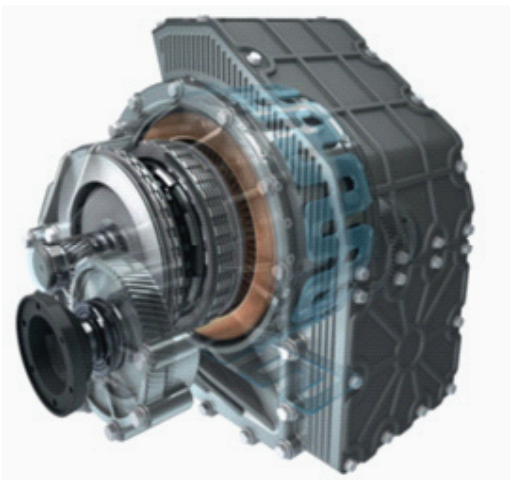
Figure 3. Single-part casted demonstrator housing designed for LPDC

- vmesnike za povezavo z menjalnikom/ pogonskim sistemom.

Zahteva po nizki teži se sooča z omejenim prostorom za montažo, kar zahteva stena debeline manj kot 3 mm, filigranske rebrne strukture (tankostenska ojačitvena rebra in rebra za zapolnjevanje, ki so omejena v največji možni meri.

Izziv predstavlja kompleksno jedro za ulivanje blokov motorjev, ki obdaja stator (gl. Sliko 4).

Za nizkotlačno litje je značilen postopek polnjenja, ki ga je mogoče dobro nadzorovati. Na podlagi preseka, ki ga je treba zapolniti, je mogoče prilagoditi optimalno hitrost polnjenja za omejevanje tvorbe zračnih žepkov in mehurjev v največji možni meri. S pomočjo številnih napajalnikov je mogoče širjenje litine po kalupu v največji možni meri omejiti z optimalnim dovajalnim postopkom in ga tako zavreti v povezavi z zmanjševanjem poroznosti. Ta postopek omogočajo številni hladilni obtoki, ki jih je mogoče nadzorovati, vdelani v orodja. Ti pomagajo prilagajati toplotni gradient pri ulivanju. Pri zapolnjevanju oblike je izjemno



Slika 4. Kompleksna zasnova hladilnega kanala

Figure 4. Complex design of a cooling channel

unfavorable positions extended to the fin junctions.

The demonstrator provides:

- Space for the stator
- Space for power electronics
- Interfaces to connect the transmission/ powertrain

The requirement “Lightweighting” is facing a limited installation space, realized by wall thicknesses below 3 mm, filigree rip structures (thin-walled stiffening rips) and filling-rips, which are reduced to a minimum.

A challenge is the complex water jacket around the stator (see figure 4).

Low Pressure Die Casting is characterized by its well controllable filling process. Depending on the cross section to be filled, the optimal filling velocity is adjustable to reduce the generation of oxide and blisters to a minimum. Using multiple riser pipes, wall-thickness accumulations spread in the casting part can be minimized through an optimal feeding process and therefore suppressed due to shrinkage of the porosity. This process is supported by multiple, controllable cooler circuits integrated in the tools. Those help to adjust the thermal gradient in the casting. The temperature of the tool also plays a major role during the form-filling. Especially for parts with thin wall thicknesses in areas far away from the riser pipe a perfect filling is only guaranteed if the tool temperature is high enough. Considering this technical conditions casting components achieve the high requirements to the mechanical properties (such as tensile strength, 0,2% yield strength, …).

The CPS® process as established method for the production of functional and highly stressable aluminum engine blocks is characterized by the combination of its design freedom, its productivity and the high mechanical properties. A specialty of the

pomembna tudi temperatura orodja. Zlasti pri delih s tankimi stenami na predelih, ki so zelo oddaljeni od napajalnika, je popolno polnjenje zagotovljeno samo v primeru zadostno visoke temperature orodja. Ob upoštevanju teh tehničnih pogojev lite komponente izpolnjujejo visoke zahteve glede mehanskih lastnosti (kot je natezna trdnost, 0,2-odstotna meja teženja itn.).

Za proces CPS®, ki je uveljavljen kot metoda za proizvodnjo funkcionalnih aluminijastih motornih blokov, ki prenesejo velike napetosti, je značilna kombinacija svobode pri zasnovi, storilnosti in visokomehanskih lastnostih. Posebnost procesa CPS® je izvedba kompleksnih in zelo natančnih geometrij kanala, ki odpira široko področje možnih aplikacij za opisano metodo. Poleg tega je kombinacija procesa CPS® z aditivno proizvodnjo jeder »brez orodja« primerna za hitro proizvodnjo prototipov. Ta tehnika omogoča hitro in učinkovito izdelavo tako različnih dizajnov kot funkcionalne prototipe. Pravzaprav se z litjem prvega dela že prikažejo funkcionalni parametri morebitnega procesa serijske proizvodnje.

Zaradi tesne povezanosti produktnih razvojnih centrov (PDC) družbe Nemak je mogoče zagotoviti hitro izvedbo od prve zasnove do prvega litja prototipov. Največji izziv je bil razvoj postopkov tehnologije litja za izvedbo teh novih komponent s pomočjo procesa CPS®. Začetna točka dela v Dillingenu je bil predhodno omenjeni model CAD demonstratorja. Na tej osnovi je bil razvit koncept postopka litja s pomočjo simulacije polnjenja in strjevanja. Hkrati je bil v produktnem razvojnem centru v Dillingenu zasnovan komplet jeder iz peska za izvedbo prvih ulitkov. Ker je bil ta postopek del notranjega projekta v okviru raziskav in razvoja, ki je še v teku, je bilo jedro izdelano s proizvodnim postopkom 3-D tiskanje. Po eni strani je bilo mogoče

CPS® process is the realization of complex and very fine channel geometries which open a wide field of possible applications for the described method. Furthermore the combination of CPS® with “tool-free” additive manufacturing of cores is suitable for a fast production of prototypes. With this technique different designs can be realized quick and efficient as functional prototypes. Virtually, with casting of the first part functional parameters of a possible serial production process are displayed.

Due to the close link of Nemak’s Product Development Centers (PDC) a fast realization from the first design to the first casting of the prototypes could be realized. The main challenge was the development of casting technology processes to realize such new components using CPS®. Starting point for the work in Dillingen was the aforementioned CAD model of the demonstrator. Based on this the conception of the casting process was developed by means of filling and solidification simulation. In parallel the core package was designed to realize first castings in the PDC in Dillingen. As this work was part of a currently running internal R&D project, 3D printing was considered as production process of the cores. On one hand it was possible to increase the knowledge in practical experience with this comparatively young technology to assess its potential for future use, on the other hand a lot of different designs e.g. the water jacket could be produced efficiently in small numbers without any additional costs for tools.

3 Battery housing

An additional application field for casting components in e-driven vehicles are battery housings. Here a competition between several manufacturing processes is

pridobiti znanje na podlagi praktičnih izkušenj s to razmeroma mlado tehnologijo za oceno njenega potenciala za prihodnjo rabo, po drugi pa bi bilo mogoče učinkovito izdelati številne različne dizajne npr. jedro za ulivanje blokov motorjev v majhnem številu brez dodatnih stroškov za orodje.

3 Ohišje akumulatorja

Dodatno področje uporabe litih komponent pri električnih vozilih so ohišja akumulatorjev. Na tem področju je mogoče pričakovati konkurenco med različnimi proizvodnimi procesi. Ni mogoče izključiti niti hibridnih rešitev, ki ulitke združujejo s pločevino in ekstrudirnimi profili. Zaradi vse večjega števila bodo ohišja razvita tudi kot modularne zasnove. Vse težje je podajati zanesljive izjave glede potrebnega števila in dimenzij teh kosov. Zdi se, da trdno drži samo dejstvo, da morajo biti ohišja opremljena z učinkovitim hladilnim sistemom zaradi velikih toplotnih izgub, ki so značilne za polno obremenjene akumulatorje. Glede na uporabo v hibridnih ali električnih vozilih morajo ohišja izpolnjevati različne zahteve. Pri snovanju teh komponent je treba upoštevati odpornost proti koroziji, neprepustnost ter zahteve glede elektromagnetne združljivosti in trkov.

Pri proizvodnji večjega števila ohišij brez kompleksnega hladilnega sistema prednjači visokotlačno litje (HPDC). Omejitev dimenzij ohišij trenutno postavljajo zmogljivosti strojev za litje (najv. 4.500 ton). Modularne zasnove, ki ponujajo možnost različnih moči in dometov, podobno kot pri motorjih z notranjim izgorevanjem, kažejo visok potencial za prihodnjo uporabo (gl. Sliko 5).

Druga možnost so hibridne rešitve. Aluminijasti ulitki v kombinaciji s profili lahko dosegajo mnogo večje dimenzije.

expected. Hybrid solutions which combine castings with metal sheet and extrusion profiles are conceivable. Caused by their increasing size, housings will also be developed as modular concepts. It is getting more and more difficult to make reliable statements regarding the number of pieces needed and dimensions of these parts. Fix seems to be only the fact, that the housings have to be equipped with an efficient cooling system due to the high heat loss caused by the batteries under full load. Depending on the use in hybrids or e-vehicles the housings have to match different demands.
Resistance against corrosion, leak proof, EMC- and crash requirements have to be considered when designing the components.

For high number production of housings without a complex cooling system High Pressure Die Casting (HPDC) is the favored process. The limit for housing dimensions is currently set by the capability of casting machines (max. 4500 T). Modular concepts which offer a possibility to differentiate in power and range, similar to internal combustion engines, show a high potential for future applications (see figure 5).
Hybrid solutions are another option. Aluminum castings are combined with profiles and reach together towards much higher dimensions. The main requirement is to have the joining technology under control.

In case complex cooling channels are required HPDC is not the preferred process anymore. Low Pressure Die Casting (LPDC) makes it possible to cast sand cores and to enclose tubes to optimize cooling characteristics. When casting tubes into aluminum a reproducible junction between casting part and insert is crucial for an efficient cooling. Figure 7 shows a demonstrator which is used for basic investigations. The complete filling of

Poglavitna zahteva je nadzor nad tehnologijo spajanja.

Če so potrebni kompleksni hladilni kanali, visokotlačno litje ni več prva izbira. Nizkotlačno litje (LPDC) omogoča litje v jedra iz peska in dodajanje cevi za optimizacijo lastnosti hlajenja. Pri ulivanju cevi v aluminij je ponovljiv spoj med ulitim delom in vstavkom ključnega pomena za zagotavljanje učinkovitega hlajenja. Na Sliki 7 je prikazan demonstrator, ki se uporablja za osnovne preiskave. Celovito polnjenje oblik in izbira materiala cevi nista edina vidika, ki ju je treba imeti pod nadzorom. Treba je razviti tudi simulacijska orodja za lažjo uporabo teh rešitev v prihodnje.

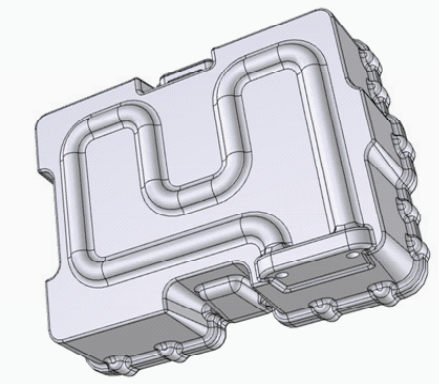
Pri uporabi peščenih jeder je popolna odstranitev peska, podobno kot pri glavah valjev in blokih, precejšen zalogaj.

Kot smo že omenili, se bo v bližnji prihodnosti razvila močna konkurenca med različnimi proizvodnimi procesi z vidika optimizacije stroškov in teže.

the forms and the material selection of the tubes is not the only challenge which has to be controlled. Furthermore the simulation tools have to be developed to facilitate the adaption of such solutions in the future.

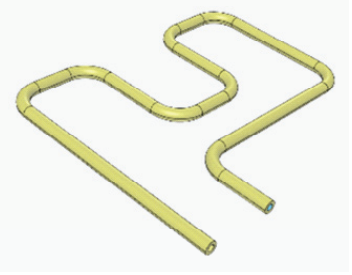
With utilization of sand cores the complete removal of the sand, similar as in cylinder heads and blocks is quite challenging.

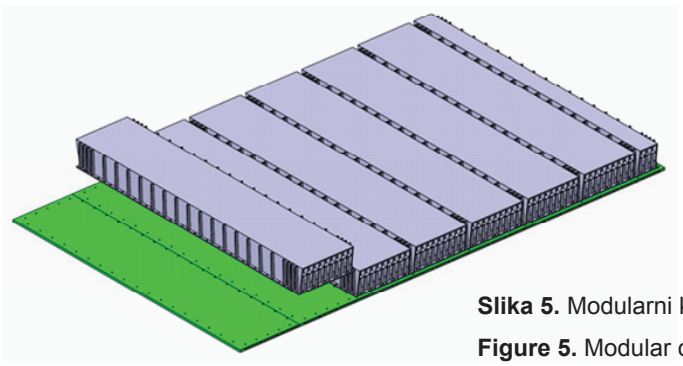
As mentioned before, there will be a strong competition between several production processes in the near future, in order to optimize costs and weight.



Slika 6. Demonstrator ohišja akumulatorja z vdelanimi hladilnimi kanali

Figure 6. Demonstrator of battery housing with integrated cooling channels





Slika 5. Modularni koncept akumulatorskega modula

Figure 5. Modular concept of battery module