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Prihodnje zahteve pri litju v trajne forme in tehnične zahteve za donosnost

Future Demands on Die Casting and Technical Requirements for its Profitability

1 Uvod

Proces tlačnega litja je tehnično zrel proces litja, ki je izjemno primeren za velikoserijsko proizvodnjo.

Trendi v smeri individualizacije izdelkov prav tako prinašajo izzive za tlačno litje. Pogostejše spremembe pri manjših serijah tako zahtevajo skorajda takojšnje povezovanje s proizvodnimi procesi predhodnih serij. Za nadaljnje dobičkonosno tlačno litje je neizogibno potrebno še dodatno poglobljeno razumevanje procesa:

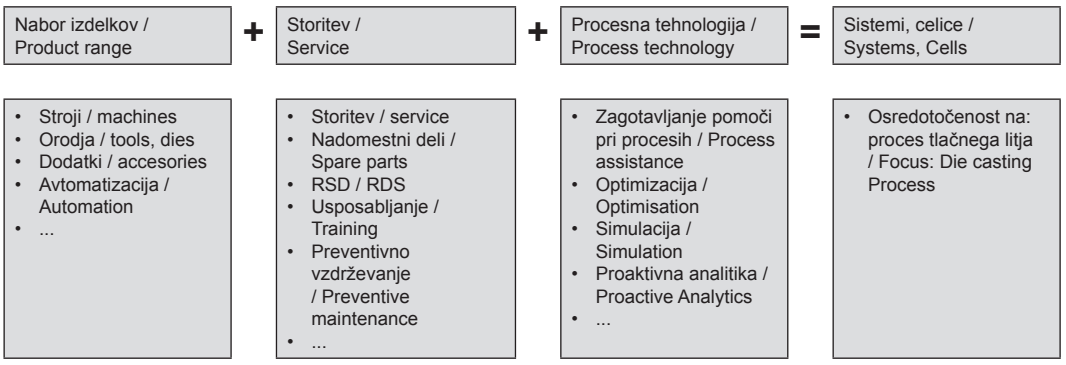
1 Introduction

The die casting process is a technically mature casting process that is excellently suited for the production of large series.

The trend towards individualization of products also means new challenges for die casting. More frequent changings for smaller series therefore require, quasi ad hoc, to be linked back to the production process of the previous batches. Inevitably, another, a deeper process understanding is needed in order to continue to be profitable in die casting:

Slika 1. Procesna veriga skupine Frech

Figure 1. Process chain of Frech Group



Slika 2. Naša filozofija

Figure 2. Our philosophy

Skupina Frech z družbo Oskar Frech GmbH + Co. KG in njenimi podružnicami (Slika 1) ima mesto v procesni verigi celice tlačnega litja. Portfelj izdelkov skupine ne zajema zgolj strojev za tlačno litje, pač pa tudi pripomočke in naprave za avtomatizacijo livne celice. To nam omogoča povezovanje znanja in izkušenj vzdolž procesne verige ter možnost, da strankam ponudimo več kot zgolj opremo za celice in prvovrstne storitve (Slika 2).

Osredotočenost skupine Frech je tako osnovana na filozofiji zagotavljanja celovite ponudbe storitev za stranke in osredotočenosti celotnega procesa na celico za tlačno litje.

2 Dobičkonosnost tlačnega litja

Na tej podlagi smo razvili proces tlačnega litja za analiziranje in prikaz poti dobičkonosnosti glede na vrsto uporabe (Slika 3).

Na podlagi naše filozofije za ogled celic procese analiziramo skupaj s stranko. Preučimo izdelek in proces, ki bi lahko bil koristen v tem smislu. Na tej osnovi so osnovne tematike analize odločilne spremenljivke, ki vplivajo na dobičkonosnost:

The Frech Group, with Oskar Frech GmbH + Co. KG and its subsidiaries (see Fig. 1), is positioned along the process chain of a die casting cell. Not only die casting machines, but also accessories and automation devices of the casting cell belong to the product portfolio of the group. This makes it possible to bundle this know-how along the process chain and to offer the customer more than just the equipment of cells and first-level services (see Fig. 2).

The focus of the Frech Group is therefore based on the philosophy of offering the customer a comprehensive range of services and focusing the entire process in the die-casting cell.

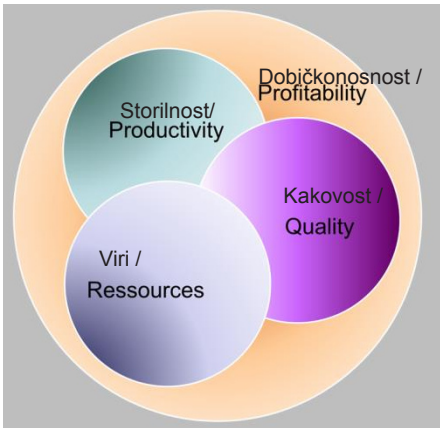
2 Profitability in Die Casting

From this, the die casting process has been developed in order to analyze and to show the path to profitability, depending on the application (see Fig. 3).

From our philosophy for cell viewing, we analyze the processes together with the customer. We consider the product and the process, which should be beneficial in this regard. On this basis, the core topics of the

- kakovost,
- viri,
- storilnost.

Za oceno, kako dobra ali slaba so ta tri področja v vaši livarni, običajno potrebujete informacije. Torej številke, podatke in dejstva, ki vam omogočajo izvedbo ocene na podlagi npr. kazalnikov. Bolj objektivni, kot so ti kazalniki, bolj zanesljivo je mogoče proces optimizirati.



Slika 3. Dobičkonosnost

Figure 3. Profitability

Te informacije lahko pokažejo tudi omejitve v trenutnem procesu. Izkušnje oziroma primerjalno znanje s podobnimi primeri morda ne zadostuje več za doseganje izboljšav. V teh primerih lahko včasih izboljšave in inovacije v tehnologiji tlačnega litja prinesejo odločilno prednost.

Kako pridobiti objektivne informacije, zanesljive številke, podatke in dejstva o predhodnih procesih?

3 Upravljanje masovnih podatkov in analitika

Tovarne v industriji tlačnega litja že desetletja upravljajo s tehnologijo digitalnega nadzora,

analysis are the decisive variables which influence the profitability:

- quality,
- resources,
- productivity.

In order to assess how well or how badly these three fields are in your foundry, you generally need information about it. That is, figures, data and facts, which allow a valuation based on, for example, indicators. The more objectively these indicators are determined, the more reliable the process can be optimized.

This information can also show limitations in the current process. Experiences, comparative knowledge with similar cases may no longer be sufficient to achieve improvements. In such cases, improvements and innovations in die casting technology can sometimes bring the decisive advantage.

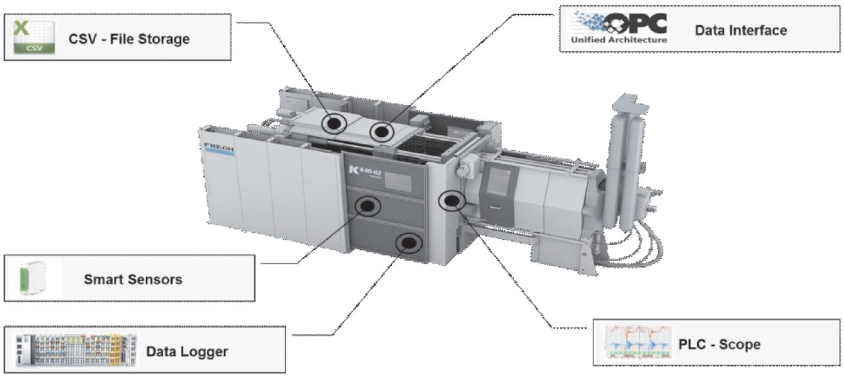
How do we get objective information, reliable figures, data and facts of the previous processes?

3 Big Data Management and Analysis

The production facilities in the die-casting industry have been equipped with digital control technology for decades. With sensors and actuators that acquire and respond to data via a programmed machine control system. Regulated machine functions are now largely standard.

The plants and die casting cells also have the possibility to store, analyze and display these data. Many people already use this in company networks and store this data centrally.

With the preceding questions, however, the question arises as to whether a process optimization can be operated with the manufacturer-dependent data of the



Slika 4. Beleženje podatkov: podatki o stroju in procesni podatki iz različnih virov

Figure 4. Data Recording: Machine and Process data from different sources

in to s tipali ter prožili, ki pridobivajo podatke prek programiranega sistema za nadzor strojev ter se nanje odzivajo. Nadzorovane funkcije strojev so v številnih primerih že osnova.

Obrati in celice za tlačno litje imajo zmožnosti shranjevanja, analiziranja in prikazovanja teh podatkov. Številni uporabniki te podatke že uporabljajo v družbenih omrežij in jih shranjujejo centralno.

Iz predhodnih vprašanj pa se porodi vprašanje, ali je proces optimizacije mogoče upravljati s podatki proizvajalca, vezanimi samo na stroje in celice. Odgovor je jasen: zagotovo ne!

Zbiranje podatkov za ta namen sega še dlje. Če je tako predvideno za namene optimizacije livarne, mora biti zbiranje celovito in zajemati tudi podatke, ki niso vezani na stroje, kot so podatki o orodju, temperaturni nadzor pri tehnologiji brizganja itn. To velja tako za sodobne in nove stroje, kot že obstoječe stroje prek sistemov vodenja dnevnikov, sodobnih vmesnikov in podatkovnih povezav (Slika 4).

Nadalje je treba na splošno upoštevati tudi preostale sisteme v celotni livarni. Torej machines and cells alone. Clear answer: certainly not!

Data collection for this purpose goes beyond this. And if it is to be used for the purpose of optimization in the foundry, it must also be more comprehensive, also to record non-machine-related data, such as data of the tool, the temperature control of the spraying technology etc. And this on modern, new machines as on existing machines, through data logger systems and modern interfaces and data interfaces (see Fig. 4).

Moreover, the overall consideration must also be thought of extending these systems to the entire foundry. That is, in a future development stage, not only the casting cell is recorded but also the logistics of the foundry, the material flow, the recycling, the production planning, etc.

This is the basis for tackling the ideas in the direction of industry 4.0 at all.

If enough data is collected, it means to evaluate it meaningfully. From data information must be taken. Information about the interactions in the process as well as the process improvement potentials (see Fig. 5).

Slika 5. Upravljanje masovnih podatkov in analitika

Figure 5. Big Data Management and Analytics

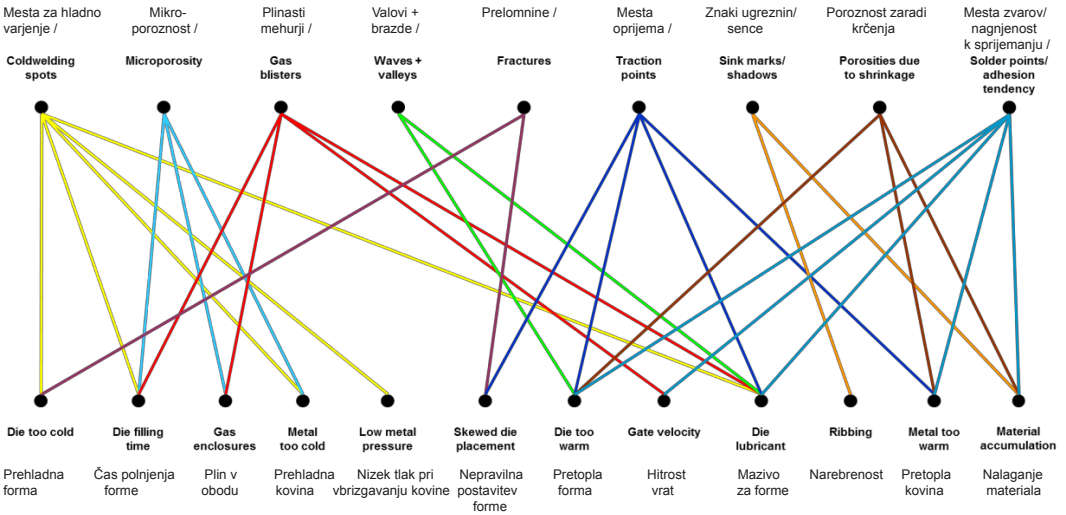
se v fazi prihodnjega razvoja ne beleži samo livarska celica, temveč tudi logistični procesi livarne, pretok materialov, recikliranje, načrtovanje proizvodnje itn.

To je osnova za to, da bomo sploh kos zamislim, vezanim na usmeritev industrije 4.0.

Če je zbrana zadostna količina podatkov, to pomeni, da jih je treba smiselno preučiti. Iz podatkov je treba zbrati informacije. To so informacije tako o interakcijah v procesih

4 Key Topics for Productivity

If the founders know these interactions in their processes, optimizations can be carried out. In many cases however they work heuristically or with pure empirical values. These methods are limited in consideration of the large number of interactions (see Fig. 6) and the unequivocal assignment of causes and effects in the die casting process.



Slika 6. Medsebojni vplivi

Figure 6. Interaction

kot potencialih za izboljšave procesov (Slika 5).

4 Ključne teme za storilnost

Če so livarji seznanjeni s temi interakcijami v njihovih procesih, je izvedba optimizacij mogoča. Vendar pa v številnih primerih delujejo hevristično ali zgolj na podlagi empiričnih vrednosti. Te metode so omejene v zvezi z velikim številom interakcij (Slika 6) ter jasno dodelitvijo vzrokov in učinkov v procesu tlačnega litja.

Pri obdelavi velikih količin podatkov lahko soodnosnost podatkov izhaja tudi iz parametrov, ki se na prvi pogled zdijo nepomembni. In po potrebi lahko iz tega izhajajo ukrepi, ki upravljavcu stroja ali obrata zagotavljajo priporočila za optimizacijo procesa prek tako imenovanih sistemov za zagotavljanje pomoči ali avtomatizacije.

Katere so tovrstne ključne tematike, ki vodijo v večjo dobičkonosnost? Članek v nadaljevanju navaja nekaj primerov, razvrstitev pa temelji na Sliki 7.

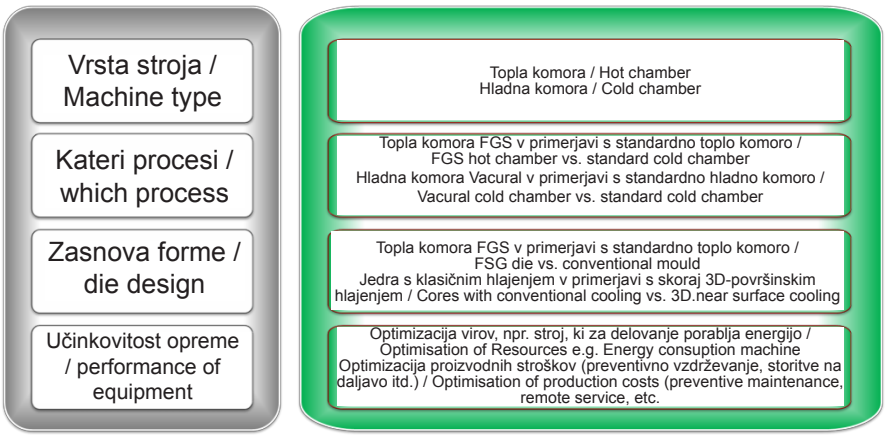
V grobem razlikujemo med naslednjimi tematikami:

When processing large amounts of data, correlations can also be derived with parameters, which do not appear relevant at first sight. And, if necessary, measures can be derived from this, which support the machine operator or plant operators with recommendations to optimize the process via so-called assistance systems or automatisms.

What are such key topics that lead to greater profitability? In the following, some examples are shown in this article, the classification being based on Fig. 7.

Mainly the following topics can be distinguished:

- **Process technology and machine technique:**
  Depending on the alloy being processed, the hot chamber and/or the cold chamber process are used for die casting. Magnesium alloys, for example, can be processed in both process technologies, which is why the spectrum of the die casting parts has to be considered in particular in order to select the optimum method. In /1/ und /2/, the authors compared the procedures for such applications and



Slika 7. Ključna področja za storilnost

Figure 7. Key fields for productivity

- **Procesna tehnologija in strojna tehnika:**
  Glede na vrsto zlitine, ki se obdeluje, se za tlačno litje uporablja proces s toplo in/ali hladno komoro. Magnezijeve zlitine se na primer lahko obdelujejo z obema procesnima tehnologijama, zato je treba razpon tlačno litih delov upoštevati zlasti pri izbiri optimalne metode. V delu /1/ in /2/ so avtorji primerjali postopke za tovrstne aplikacije in določili merila za izbiro.
- **Tematike, vezane na proces:**
  Na podlagi primernih in inovativnih metod lahko izkoristimo prednosti in izboljšave v primerjavi s standardnim procesom tlačnega litja. Sistem FGS ali proces Vacural® je inovativna procesna tehnika, ki omogoča izboljšano storilnost v primerjavi s standardnim procesom litja.
- **Forma za tlačno litje:**
  Forma je ključni element tlačnega litja. Kakovost delov in učinkovitost litja posledično nista nepomembni. Zasnova forme s simulacijo polnjenja je dandanes standardni element. Holistični pogled na vsebnost toplote in nadzor temperature pri formi sta ključnega pomena za proizvodnjo, vendar se pogosto določata skladno s klasično metodologijo. Sistem FGS, tj. sistem z vročim dovodnim kanalom za spremenjeni proces tlačnega litja z vročo komoro (proces FGS), kaže potencial za gospodarnejše tlačno litje, pa tudi za tehnologijo 3D-konformnega tempranja kalupa.
- **Učinkovitost opreme:**
  Ta tematika je precej obsežna. Vendar pa je učinkovitost odvisna tudi od procesa in procesne konkurenčnosti dobavitelja opreme za zagotavljanje zadevnih storitev livarju za optimizacijo virov in stroškov.

gave criteria for selection.

- **Process topics:**
  By means of suitable, innovative methods, advantages and improvements can be used compared to the standard die casting process. The FGS system or the Vacural® process are innovative process techniques that perform more than the respective standard casting process.
- **Die casting die:**
  The die is a key element in die casting. The quality of the parts and the efficiency of the casting are thereby determined not insignificantly. The design of the die by means of filling simulation is nowadays a standard feature. The holistic view of the thermal household and the temperature control of the die are essential for production, but they are often determined according to classical methodology.
  The FGS system, a hot-runner system for a modified hot chamber die casting process (FGS process), shows potentials for more economical die casting as well as the technology of 3D conformal tempering the mold.
- **Performance Equipment:**
  Beneath this a lot can be summarized. However, it also depends on the process and process competence of the equipment supplier to provide respective services to the caster to optimize the resources and costs.

5 Examples for Optimizing of the Die Casting Process

Frech not only offers its customers a broad product portfolio, but also the support of innovation and services in exactly, what are the core and key topics which are suitable

5 Primeri optimizacije procesa tlačnega litja

Skupina Frech svojim strankam ne ponuja zgolj obsežnega portfelja izdelkov, pač pa tudi podporo pri inoviranju in pomoč pri ugotavljanju, katere so osnovne in ključne tematike za optimizacijo procesa tlačnega litja. Sledi nekaj primerov:

5.1 Inovativni FGS

FGS, kratica za Frech Gating System (sistem z dovodnim kanalom Frech), je patentirani sistem z vročim dovodnim kanalom, ki ga je družba Frech razvila za visokotlačno litje neželeznih kovin v procesu, ki se izvaja v topli komori (/3/).

Zaradi sistema z dovodnim kanalom brez odklonskega ventila v formi po eni strani in privzetega procesnega vodila po drugi se široko izognemo običajnemu dolivku in velikim delom dovodnega kanala (Slika 8). To običajno pomeni, da teh odstranjenih

5 Examples of optimization of the die-casting process

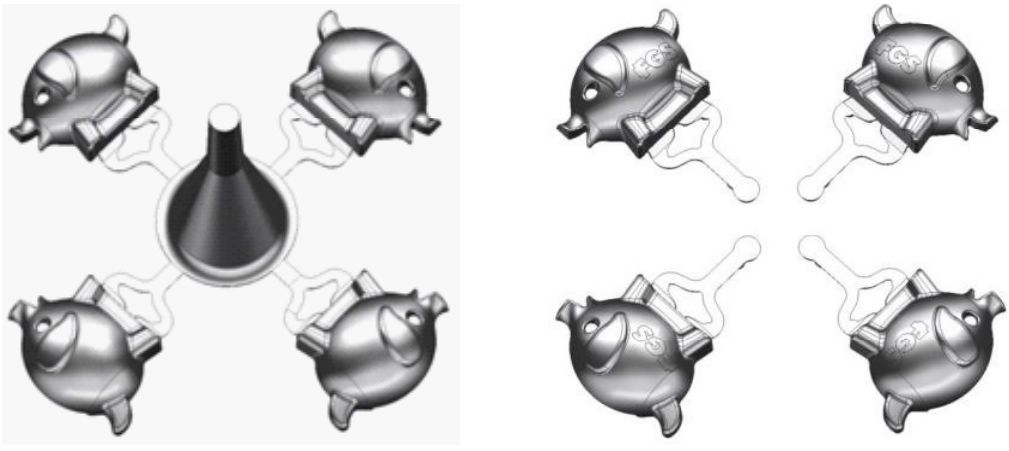
The Frech group offers its customers not only a comprehensive portfolio of products, but also support in innovation and assistance in finding solutions, which are the basic and crucial topics to optimize the die-casting process. Here are some examples:

5.1 Innovation FGS

FGS, which stands for Frech Gating System, is a patented hot runner system developed by Frech for non-ferrous metal high pressure die casting in the hot chamber process (/3/).

By means of a reject-valve-free hot-runner system in the die on the one hand and by an adapted process guide on the other hand, the usual sprue of the casting and large parts of the runner are clearly avoided (see Fig. 8). This generally means that these eliminated runner components do not have to be recycled during the manufacturing process. This means, there is no effort required in the form of work incidents, handling and process costs, recycling, re-melting costs, etc.

The melt is also always kept at the gate. Thus, the venting expense in the die



Standardni / Standard FGS

Slika 8. Prikaz klasičnega dovodnega kanala v primerjavi z dovodnim kanalom FGS

Figure 8. Scheme classical gating versus FGS

komponent dovodnega kanala med proizvodnim procesom ni treba reciklirati. To tudi pomeni, da odpadejo težave, vezane na nesreče pri delu, ravnanje in stroške obdelave, recikliranje, stroške ponovnega taljenja itn.

Talina v vsakem trenutku ostaja v dovodnem kanalu. Zato je strošek zračenja v formi omejen s količino zraka v livni votlini. Proces litja FGS ne zahteva več tako imenovane »prve faze«, pri kateri se standardni proces s toplo komoro uporablja za prenos taline, npr. brez zvrtinčenja zraka do dovodnega kanala pri zmerni hitrosti. To privede do manjše poroznosti, krajših ciklov, večjega števila izdelkov boljše kakovosti. Slika 9 prikazuje preplet prednosti tudi glede porabe energije, kakovosti delov, učinkovitosti procesa in storilnosti.

5.2 Proces Vacural® za tlačno litje z visokonapeto hladno komoro

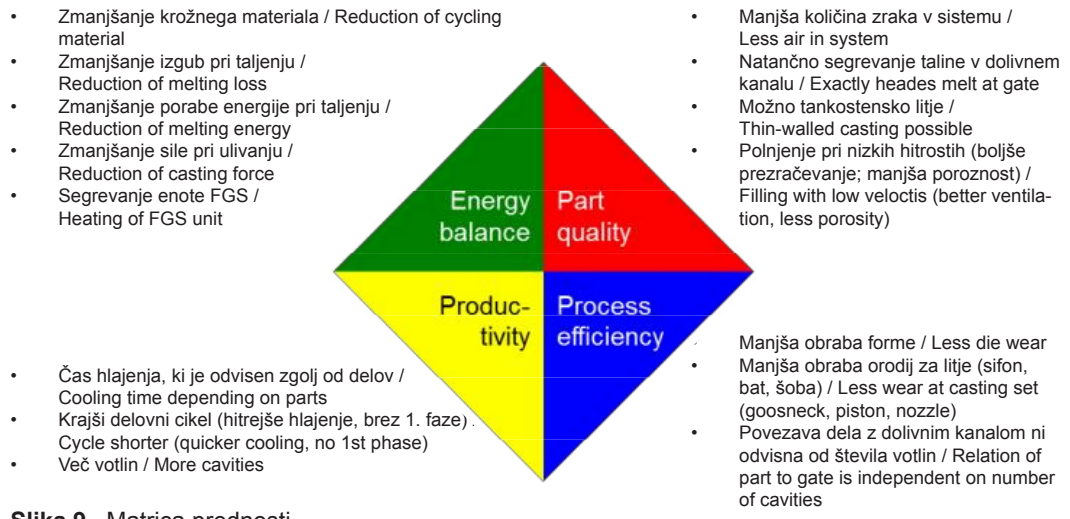
Slika 10 prikazuje načela te posebne metode pri tlačnem litju s hladno komoro. Za tlačno

is limited to the air volume of the cavity. The FGS casting process no longer requires a so-called „first phase“, which in the standard hot chamber process serves to transport the melt e. g. without air turbulence to the gate at a moderate rate. That is, less porosity, shorter cycles, higher parts yield with better quality. Fig. 9 shows the complexity of the advantages also in terms of energy consumption, part quality, process efficiency and productivity.

5.2 Vacural® Process for Highly-Stressed Cold Chamber Die Casting

Fig. 10 shows the principle of this special method in cold chamber die casting. Characteristic for Vacural® die casting is the extremely low porosity of the parts and the very good suitability for very thin-walled parts. The casting products in the Vacural® process are characterized by a high ductility among others.

In the Vacural® process the melt is sucked from a holding furnace via a

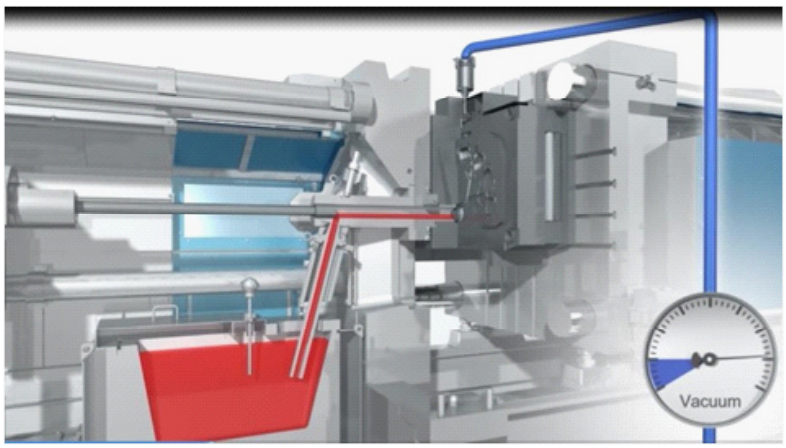


Slika 9. Matrica prednosti

Figure 9. Matrix of advantages

Slika 10. Proces Vacural®

Figure 10. Vacural® Process



litje Vacural® je značilna izjemno nizka poroznost delov in zelo visoka primernost metode za dele z zelo tankimi stenami. Za ulitke, izdelane z metodo Vacural,® je med drugim značilna visoka tanljivost.

Pri procesu Vacural® se ulitek prek povezanega podtlaka v formi posesa iz zadrževalne poti in pošlje v cev hladne komore stroja za tlačno litje. To pomeni, da se v nasprotju z metodo standardne hladne komore z naknadnim vakuumom votlina forme in cev izpraznita celo pred odmerjanjem kovine. Vakuum v sistemu slabi nagnjenosti k oksidaciji taline v cevi in podpira odvajanje plina. Oba dejavnika trajno učinkujeta na kakovost ulitka.

5.3 Konformno tempranje forme

Dober primer so jedra, zatiči ali drsniki v formi, ki jih je zaradi njihove geometrije pogosto mogoče temprati samo posredno ali pomanjkljivo (Slika 11). Posledično so te komponente izjemno toplotno obremenjene in se v primerjavi z življenjsko dobo forme razmeroma hitro obrabijo.

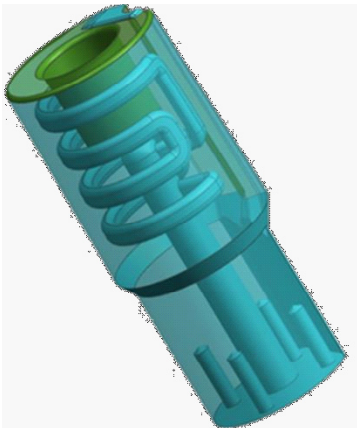
Če se jedra zdaj proizvajajo npr. s procesi aditivne proizvodnje, ki zajemajo hladilne kanale v bližini površine skladno z

connected vacuum on the die and is dosed into the sleeve of the cold chamber die casting machine. That is, in contrast to the standard cold chamber method with a downstream vacuum, the cavity of the die and the sleeve are evacuated here even before the metal dosing. The vacuum in the system counteracts the oxidation tendency of the melt in the sleeve and supports its degassing. Both factors have a lasting effect on the casting quality.

5.3 Conformal Die Tempering

A good example here are cores, pins or slides in a die which can often be tempered only indirectly or deficient due to their geometry (see Fig. 11). As a result, these components are thermally extremely stressed and wear relatively quickly compared to the lifetime of the die.

If cores are now produced, for example by means of additive production processes which contain cooling channels close to the surface in accordance with their contour, their lifetimes can be significantly increased. If the lifetime is the same as for the die, additional maintenance may be omitted;



Slika 11. Primer jedra s konformnim hlajenjem
Figure 11. Example for a core with conformal cooling

njihovo konturo, se lahko njihova življenjska doba bistveno podaljša. Če je življenjska doba enaka kot za formo, je mogoče izločiti dodatno vzdrževanje. Procesov litja ni treba deliti v serije; izogib stroškom postavitve in dodatmin stroškom popravil.

Poleg tega boljše sproščanje temperature običajno omogoča hitrejši proizvodni cikel. To pomeni, da so celice bolj storilne. Dobra razporeditev temperature tudi izboljša površino ulitka, ki v določenih primerih privede do sprožitve manjšega obsega odpadkov. Rezultat so »številne koristi« za dobičkonosnost procesa.

5.4 Prihranki pri virih, npr. energiji

V industriji tlačnega litja ni nenavaden pojav delo s stroji, starejšimi od 30 let. Vendar pa so pogosto v remontih. Toda ali se je tehnologija prilagodila najnovejšemu tehnološkemu stanju, če je to sploh mogoče? Ali se je zgolj ohranil »status quo«?

Slika 12 prikazuje vpliv različnih tehnologij na pogon stroja za tlačno litje s silo utopa 16 MN. Zgoraj levo je prikazana energijska poraba pri delovnem ciklu obstoječega starejšega stroja. V preteklosti se je navadno uporabljala tehnologija s

Casting processes do not have to be divided into batches; Additional setup costs and additional repair costs will be omitted.

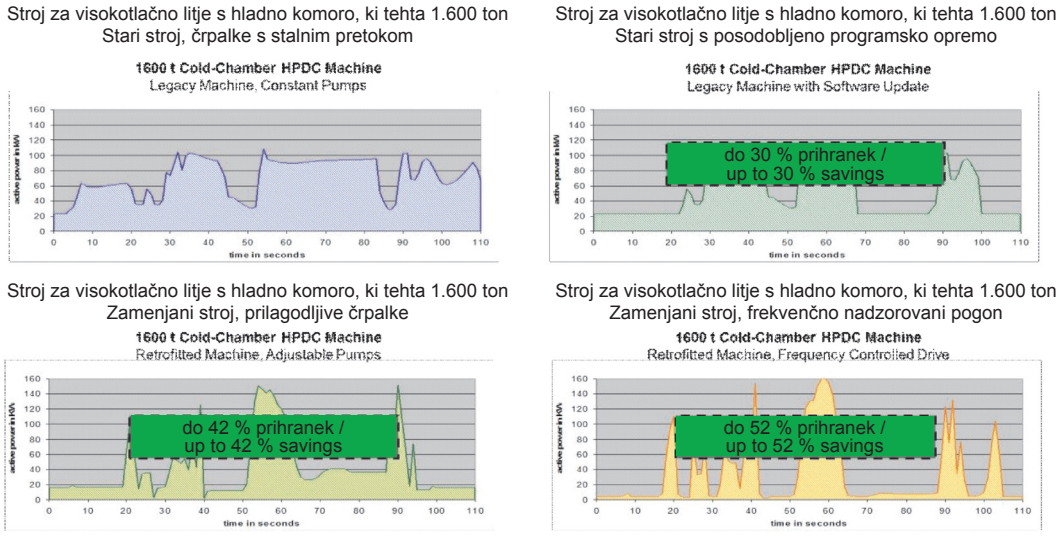
In addition, the better temperature release usually allows a faster production cycle. This means, the cell works more productively. The good heat dissipation also improves the surface of the casting, which in some cases leads to a sustained reduction in the scrap rate. That is, „multiple benefits“ in the profitability of the process.

5.4 Savings in Resources, e. g. Energy

In the die casting industry it is not unusual to produce with machines older than 30 years. Often they are overhauled in the meantime. But was the technology adapted to the latest state of technology, if possible? Or was only the status quo conserved?

Fig. 12 illustrates the effects of different technologies on the machine drive of a die casting machine with a locking force of 16 MN. At the top left is the energy consumption of a working cycle of an existing machine of older years. The common technology of the early days was a constant-pump drive with high-low-pressure switchover.

Only modern software optimization and modifications to the machine control system



Slika 12. Zmogljivost – prihranki pri virih

Figure 12. Performance - Savings in Resources

stalnim črpalnim pogonom z menjavanjem visokega in nizkega tlaka.

Samo z optimizacijo sodobne programske opreme in spremembami sistema krmiljenja motorja lahko prihranimo 30 % energije na delovni cikel (prikazano zgoraj desno). Prihranki so lahko še večji v primeru prilagoditve črpalnega sistema ali uporabe popolnoma nove tehnologije pogona v strojih najnovejših generacij. V tem primeru je mogoč energetski prihranek 53 % na delovni cikel. Vendar pa je treba za oceno te pomembne metode izmeriti energijsko porabo obstoječe tovarne in jo analizirati v primerjavi z ustreznimi izhodišči.

5.5 Upravljanje stroškov

Predhodne analize in metode niso omejene na strojne pogone. Na ta način je mogoče zaznati in oceniti celotne livne celice, pri tem pa lahko upravljavec vidi, kje so potenciali za

can save 30% of energy in the cycle (shown in the upper right figure). The savings can be further increased, if the pumping system is adapted or when a completely new drive technology of today‘s machine generations is retrofitted. In this case, up to 53% of the energy consumption of the working cycle can be saved. However, in order to evaluate this in a meaningful manner, it is necessary to measure the energy consumption of the existing plant and to analyze it in comparison to corresponding benchmarks.

5.5 Cost Management

The previous analyzes and methods are not limited to the machine drive. In this way, entire casting cells can be detected and evaluated so that the operator can see where the optimization potentials lie in the respective casting process of a part. They are not the same per se, but depend heavily on the product.

optimizacijo pri zadevnem livnem procesu. Ti potenciali med seboj niso popolnoma enaki, pač pa so močno odvisni od izdelka.

Vse te analize pa je mogoče pretvoriti tudi v strošek na izdelavo dela oziroma bolje rečeno strošek na izdelavo kakovostnega dela – tako zagotovimo preglednost.

Orodja za to postajajo na voljo z vse večjo digitalizacijo, ki omogoča beleženje podatkov o celici, procesu in kakovosti, na podlagi katerih lahko osnujemo zaključke.

6 Povzetek

Zgornji primeri prikazujejo nekaj orodij za izboljšavo dobičkonosnosti tlačnega litja tako s ciljno usmerjenimi inovacijami kot v primerjavi z izhodišči. Uporabni so podatki o procesu, iz katerih lahko pridobimo zanesljive in objektivne informacije ter ki se lahko uporabljajo za ciljno usmerjene izboljšave.

Na voljo je tehnologija za ustvarjanje informacij iz podanih podatkov. Za tvorbo pravilnih sklepov je potrebno tudi razumevanje in poznavanje različnih področij tlačnega litja. V tem smislu je Skupina Frech organizirana skladno za uvajanje nenehnih izboljšav tlačnega litja skupaj s strankami ter za postavitev livarstva kot sodobne industrije za prihodnost z inovacijami in novitetami.

All these analyzes can, however, be converted at the cost per part – or better at the cost per good part - so that transparency is generated.

The tools for this are available with increasing digitization in order to record cell, process and quality data, and then draw conclusions from them.

6 Summary

The previous examples have shown some instruments on how to improve the profitability of die casting by means of targeted innovations, but also by benchmark comparisons. Process data from which you can obtain reliable, objective information and which can then be used for the purpose-oriented improvements are helpful.

The technology for data-based information generation is available. In order to draw the right conclusions, there is generally also a need for understanding and knowledge in the various fields of die casting. In this respect, the Frech Group is set up in accordance with this in order to continually improve die casting together with our customers and to position it as a modern industry for the future through innovations and novelties.

Viri / Literature

/1/ Casting Symposium Aalen (Aalener Gießerei Symposium 2001: R. Fink. N. Erhard: Casting of Magnesium Alloys on Hot Chamber and Cold Chamber Die Casting Machines

/2/ IMA 2014 World Conference Proceedings: N. Erhard, M. Schlotterbeck, C. Bark: Magnesium Die Casting Technologies: A Comparison based on Parts Requirements as well as Perspective on Innovation Potential of Magnesium Die Casting

/3/ Casting Plant & Technology 1/2012: N. Erhard, D. Gerwig: FGS – high-pressure die casting without gate