OCN-25 furnace system from ABP Induction.

New perspectives for steel by low-pressure pouring

Gravity pouring is still the dominant process for the production of cast steel materials. The principle is simple and has remained basically unchanged for several centuries. However: To comply with filigree and complex component geometries as well as increasing quality demands, the process-related limitations lead to significant challenges for foundry staff and foundry engineers. Consequently, achieving the target geometry is only possible by using large quantities of liquid material with, in some cases, simultaneously high rejection rates. A consequent alternative is low-pressure pouring.

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Photos and Graphics: ABP

Low-pressure pouring of aluminum components is state-of-the-art, with a recycling material content of less than 20 percent of the weight of the component, compared with 100 percent for gravity pouring [1]. The capacities saved in the area of melting result in valuable savings and additional sales potential for the foundries.

Cast steel as a material in lightweight mold construction

Given the intensified focus on lightweight construction in the automotive sector, it is also interesting to look at thin-walled cast steel as a material: Although composite materials such as CFRP (Carbon fiber reinforced polymer) and lightweight materials such as aluminum or magnesium have outstanding lightweight construction potential, both materials also have numerous drawbacks in comparison with steel. For one thing, the primary material is significantly more expensive and the joining technology to adjacent components is more complex. In the case of construction material mixes, this requires additi-

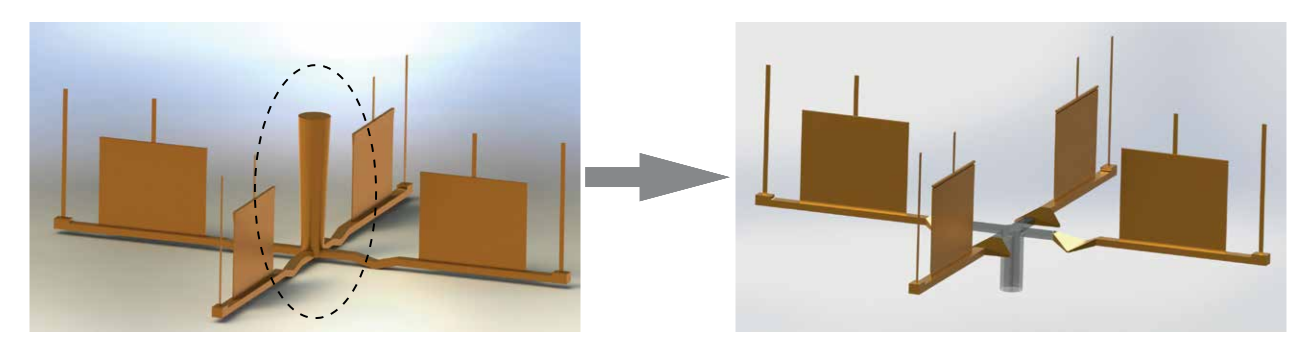

Figure 1: Stylized illustration of the savings of recycling material for thin-walled components.

Table 1: Comparison of process parameters between gravity and low-pressure pouring.

Points	Gravity pouring	Low-pressure pour
Output	20 % - 50 %	Increased by a factor of 1.5 -2
Share of rejects (depending on geometry)	Up to 25 % depending on geometry	Reduced by a factor of 5-10 % through laminar and reproducible mold filling
Form layout (with several components per mold)	A continuous casting cluster → Separation necessary	Separated parts → No separation necessary
Rework	Large feeder and gating systems	Smaller systems Final dimension sewing
Filter	Required	Not required
Melting furnace temperature	1700 – 1750 °C → higher energy consumption → short durability of the refractory lining	approx. 1640 °C → lower energy consumption → longer durability of the refractory material
Reproducibility/ repeatability	- No controlled flow rate - Temperature fluctuations during des Prozesses during the process	- Controlled low- turbulence pressure curve - Temperature control possible
Wall thickness	Thin wall thicknesses cannot be produced economically	< 2 mm and <1 mm local

onal costs for corrosion protection and makes repair concepts more expensive [2]. Materials such as aluminum are also not suitable for all cast parts (e.g. turbocharger housings). By low pressure pouring, steel components can be cast in a way that is load-bearing and has thinner walls. Thus, the material can bring about a significant advantage: It is easy to handle in common and globally available final assembly processes and suitable for fast repairs. It is therefore worthwhile to take a look at steel processing in low-pressure pouring processes.

Good reasons for low-pressure pouring

One major advantage of low-pressure pouring, as already mentioned in the introduction, is the smaller sprue/feeder system (Figure 1) and thus the smaller amount of circulation material. However, less circulation material not only means that less feedstock is required and production costs are reduced, but also that the costs of the downstream process steps (separating, fettling, deburring, ...) are significantly reduced [3] (Table 1). Due to the potential for lightweight construction, the share of low-pressure pouring in aluminum processing is rising steadily. Gravity pouring in the aluminum sector is used today for well below 50 percent of components.

Low-pressure pouring opens up the possibility of pouring thin-walled parts. „In automotive engineering, this means that structural components as well as nodal elements in the chassis area and also axle components are becoming the direct focus of attention," explains Franz-Josef Wöstmann [4], Head of the Foundry Technology and Lightweight Construction Department at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM). In his opinion, steel demonstrates its unique combination of high strength, ductility and rigidity in thin-walled production. He believes this applies not only to the passenger car sector but to the commercial vehicle sector as well. The additional advantage here is that the more rigid structures allow higher payloads and are therefore more efficient and resource-saving in operation.

In mechanical and plant engineering, various machine components up to the drives, especially for high torque motors, could be cast, which in turn could also be used in the automotive industry in the future. The application of the low-pressure pouring process is not only confined to thin-walled lightweight components. The essential advantages, such as low-turbulence mold filling, reduced gating and feeder systems and adjustable and reproducible pouring conditions are equally beneficial for virtually all other areas of application in cast steel. IFAM has already built two prototype systems and is further developing these for use in cast steel. This gives interested parties the opportunity to test their own components in low-pressure pouring without being subject to the boundary conditions and restrictions of ongoing production. It is now possible for the

Figure 2: **Illustration of the modular OCN system for highest system availability.**

first time not only to simulate the technical and economic advantages of the process.

The environmental factor also plays a major role: Minimizing of circulation and scrap material reduce the energy required per kilogram of good castings by up to 50 percent. Finally, lower quantities of liquid material and lower pouring temperatures mean that less molding material is required, which is also a major driver of energy consumption and costs. „Feedback from our customers shows that the advantages mentioned substantially increase the cost-effectiveness of the process in comparison to gravity pouring," explains Dr. Marco Rische, CTO at ABP Induction. In low pressure pouring, the core process is encapsulated, thus minimizing problems with sparking, splashing and emissions for employees during the pouring process. In terms of environmental and sustainability aspects, thin-walled production directly addresses high-strength lightweight construction, which helps to reduce fuel and energy consumption during operation. In terms of production, the possible wall thickness reduction in the design process further reduces energy and material requirements. In comparison to competitor processes, this makes it possible to dispense with mixed construction variants or composite materials involving costly recycling processes. As you can see, it is ultimately also about the interaction of these operational and environmental requirements with quality and cost factors of mass production as well as design aspects.

The OCN furnace system from ABP Induction

„The OCN furnace system was developed on the basis of the established ABP pouring furnaces in order to enable the low-pressure pouring process to be used in cast steel," explains ABP CTO Dr. Marco Rische. This is the only system for low-pressure pouring of steel castings to date that has proven itself in industrial practice after extensive preliminary tests [5,6]. Depending on the design, it offers a useful capacity of 1,000 to 10,000 kilograms. The furnace system with modern IGBT converter technology is designed for steel, iron and non-ferrous castings. The pouring of bronze and copper components is also possible with the mentioned benefits.

Components with a thickness of up to 0.8 millimeters have been realized by low-pressure pouring. The average in practice has currently settled at an average of 1.5 to 2 millimeters, for components with a length of up to 1.2 meters. Thanks to the ABP pressure control, corresponding casting molds can be entirely filled within a few seconds, without the risk of imperfections or porosities if the process is properly controlled. Low-pressure pouring thus enables complex and weight-optimized geometries to an extent similar to that of precision pouring. In contrast, the significantly lower manufacturing costs of low-pressure pouring components and the possibility of producing thin-walled components in almost any size.

The OCN low-pressure pouring furnace is designed according to the Teapot principle (Figure 2). This offers considerable benefits in operation. Besides the high buffering capacity, the possibility of depositing residual slag in the furnace vessel and slag-free pouring without the risk of freezing have also proved successful in practical applications. Furthermore, the crucible inductor allows the OCN furnace system to be completely emptied quickly, e.g. for an alloy change. Last but not least, the furnace has a modular design so that the individual elements can be replaced easily and quickly at the end of their respective refractory life and the system is highly available.

From practice: Initial experience

In contrast to gravity pouring, the low-pressure pouring process is automated to a high extent. Mold filling is pressure-controlled and the temperature can be regulated within a minimum tolerance range. This process therefore resolves the challenge posed by unregulated temperature, because in the high temperature range there is a higher risk of gas porosity, sand inclusions, rough surfaces or even mechanical adhesion, while in the low temperature range, there is a risk of crack formation and inadequate mold filling. In the OCN system, the metal in the furnace is contained in a closed container with a protective gas atmosphere. This means that the melt absorbs less hydrogen and other impurities and the oxide formation is minimized. This is the basis for good pouring quality. In addition, materials can also be cast which could not be poured in conventional processes because of their high oxidation tendency, i.e. including copper alloys with an affinity for oxygen.

The pressure curve for controlling the mold filling can be individually adapted and archived for each casting mold. The low-pressure control works with proportional technology and achieves accuracies of ±1 mbar. „The support points of the pressure curve can be adjusted in the range of tenths of a second", says Dietmar Mitschulat, software engineer at ABP Induction responsible for programming the control of the OCN system. What he also values: „With every pouring process, there is an automatic comparison of target and actual values." Additional production values (furnace pressure at start, target pressure, actual pressure, argon consumption during pouring, mold contact pressure target and actual, temperature during pouring) are archived and can be used for continuous impro-

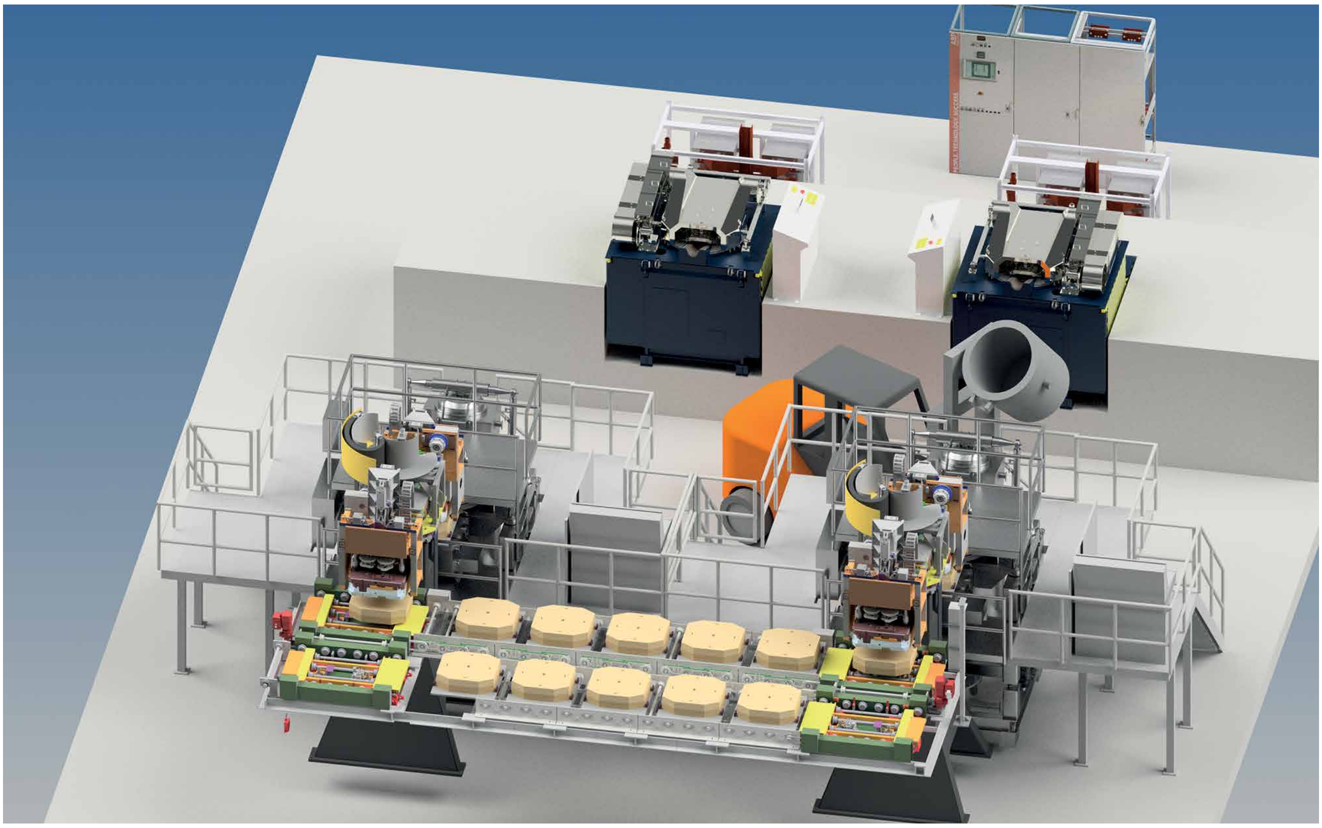

Figure 3: **Integration of the OCN system into an existing plant.**

vement of the pouring result. „As such, this makes it possible to sustainably reduce liquid metal content and it guarantees minimum process-related scrap rates. Moreover, the process ensures the highest possible reproducibility and automation in line with the principles of modern Industry 4.0 production".

Other empirical values from practice arise with regard to the company organization and the production process:

> Pouring in short cycle times with low manpower requirements increases the productivity of the foundry,
> Relief of staff: Work processes with a high level of concentration and repetitive procedures can be automated and continuously optimized,
> The size of the gating and feeder system can be reduced, thus reducing the amount of circulation material,
> When filling the molds, pouring underfills are avoided, which reduces the reject rate,
> Turbulence-free entry of the melt into the gating system,
> Complete mold filling in the shortest possible time, especially for complex and thin-walled castings,
> Consistent pouring temperature.
> Possibility of adapting existing production lines (Figure 3)

Conclusion

When comparing conventional processes based on the principle of gravity pouring on the one hand and the future-oriented low-pressure pouring process on the other, the benefits for the latter process are obvious. It shows that low-pressure pouring can be used to make steel castings fit for future requirements, also in automotive engineering and the related supply industry. This is especially relevant given the enormous market and margin pressure on the remaining components of the combustion engine. In the practice of low-pressure pouring, this means that a wide range of new opportunities are opening up for the production of steel castings. On the one hand, this is the optimization of existing component series and types for a cost and resource efficient production using the low-pressure pouring process. At the same time, there is also the opportunity to open up new markets in comparison to alternative production methods and to maintain competitive markets.

This makes it possible to produce lightweight structures made of high-strength materials, especially for large series in the automotive industry, as well as thin-walled castings, which are an important prerequisite for future applications based on the changing requirements of e-mobility. Thin-walled steel castings offer the most favorable compromise between design on the one hand and component and system costs on the other. This is especially true for junctions and connecting elements of the body-in-white [7] as well as other structurally relevant parts of future e-mobility vehicles in the passenger car and commercial vehicle sector.

In terms of the environment and sustainability, low-pressure pouring not only saves energy compared to conventional processes due to the smaller quantities of input material. As the CO2 emissions from steel production are about six times lower than those from the manufacture of comparable aluminum products, lightweight steel casting is gaining enormously in importance, especially in times when resource and energy efficiency are of the essence. The time factor is also important: Those who act now can seize the opportunity for a unique selling proposition - and the development of new castings and markets.

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