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Development of Casting Product Using Reverse Engineering Technology: A Case Study

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Abstract. *One solution to increase domestic industry competitiveness and performance is mastering reverse engineering (RE) technology. Through mastery of this technology, the use of domestic components will increase. However, this is still an obstacle due to a weak understanding of RE technology and the availability of RE facilities. This article will examine the RE process of a casting product and optimize the product manufacturing process through simulation with casting software for the High-Pressure Die Casting (HPDC) process with a case study of a top body converter product. This research begins with product identification, development, and optimization. The next step is to determine the design and injection parameters to be simulated in the Inspire casting software and then design the HPDC mold. Through RE technology, this research has produced an optimal top body converter product with a weight 36% lighter than the initial weight, and an HPDC mold design for the optimal product has been produced.*

Keywords: *product development; casting product; reverse engineering; manufacturing process simulation; HPDC.*

I. INTRODUCTION

Indonesia, as one of the largest developing countries in the world, continues to strive for industrial transformation to achieve status as an advanced industrial country. Indonesia needs to increase innovation activities, product development, and patent creation, which can encourage long-term economic growth. (Nugroho et al., 2023). One effort to achieve this is by optimizing the use of domestic components, but if you look at the facts so far, the level of domestic component content is only around 30% (Prasetyo et al., 2016). This is still below the minimum Domestic Component Level (TKDN) value, stated in the 2018 Presidential Regulation, which states that the lowest TKDN value is 40%. The obstacle preventing national industry from developing is the lack of mastery of technology and product development expertise.

One product development method in the manufacturing world is reverse engineering (RE). Reverse engineering analyzes an existing product as a basis for designing new, similar products to minimize weaknesses and optimize the product (Daywin et al., 2019).

To improve skills, understanding, and mastery of the reverse engineering process, this article will examine the stages of the product development and optimization process along with manufacturing process simulations for High-Pressure Die Casting (HPDC) technology with a case study of a top body converter. This study was carried out in several stages, starting from product identification, then carrying out the first stage of development, which involved the RE process to obtain the geometry to produce the product prototype, then optimizing the prototype product that had been produced until the optimal product mold design was reached. This research outputs an optimal product design validated by design studies and HPDC molds for the product.

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II. RESEARCH METHOD

This research was carried out in several stages, as seen in Figure 1.

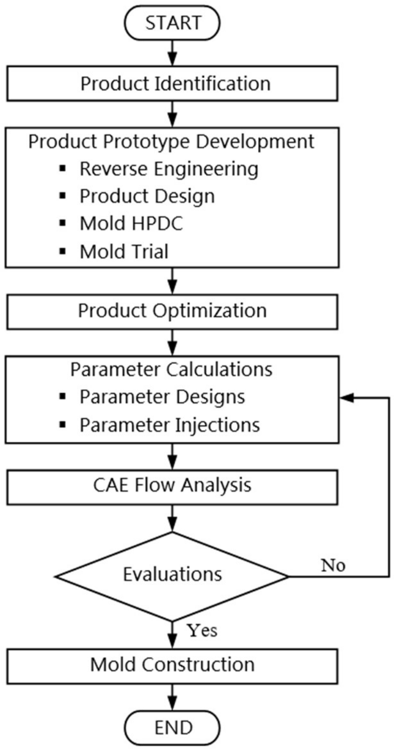


Figure 1. Research metodology

This research begins by identifying the product to obtain data regarding the product's function, the features of the product, and the characteristics required for the product. The output of this stage is product specifications. Specifications or a list of demands are needed to achieve functions and do not exceed the specified limits, as done by (Kurniawati et al., 2018).

The next stage is developing a prototype of the product that will be produced. The aim of making this prototype is so that the product can be evaluated directly from product design to the product manufacturing process. This stage begins with reverse engineering activities to obtain product geometry data through scanning processes, product design and development processes, temporary molds, and trials. The equipment used in this activity includes the MetraSCAN Black Elite 750 3D scanning machine, Vxelement 11 software, Creo parametric 9, 3D printing machine type of form 3L, other supporting tools such as the Formlabs curing machine, and the Formlabs washing machine in the Reverse Engineering and Product Development Laboratory at the Department of Manufacturing Design Engineering, Polman Bandung. The scanning process can be seen in Figure 2. The output of this stage is the design of a product so that it can be continued through the trial process with HPDC technology.

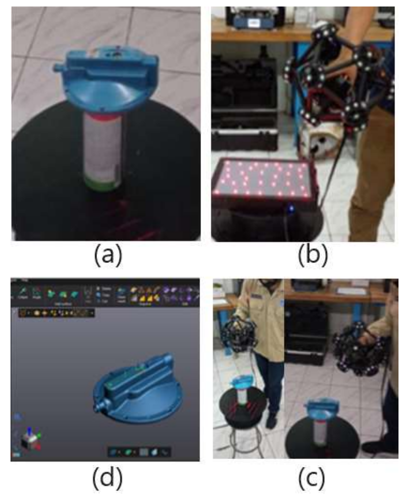


Figure 2. 3D scanning process: (a) product placement; (b) tool calibration; (c) scanning process; (d) product geometry editing.

Next, the product optimization stage uses design studies in SolidWorks software. Optimization is carried out to obtain optimal product weight. The design study stage begins by identifying design variables, namely data on rib thickness, hole thickness, and valve seat thickness. Stress with a maximum value of 100 MPa was selected to identify design constraints. If it exceeds this value, the safety factor that occurs will be less than the specified one, namely 1.5, and will result in a risk of failure due to the low safety factor as done by (Mulyanto & Sapto, 2017). Next, the optimization target set is the total product weight of the top body converter product.

At the calculation stage, the parameters consist of two groups: design parameters related to the product and injection parameters related to the product manufacturing process. These two parameters are essential to control because they will affect the product formation process and the strength value of the product itself (Adamane et al., 2015). The design parameters that need to be calculated and controlled are shrinkage, overflow, gate system, runner system, filling ratio, clamping force, shot volume length, slow approach length, and die filling.

The next stage is to conduct finite element material flow analysis during the injection process. In this research, simulations were carried out using Inspire Cast software. The results of this simulation will be evaluated to assess whether the product can be produced adequately using HPDC technology.

The final stage is to design the mold construction based on the parameters determined in the previous stage. The mold is designed with a slider system to produce products close to the finished product, making it also more optimal.

III. RESULT AND DISCUSSION

Product Identifications

Table 1 shows the results of product identification in the form of specifications or a list of demands for top-body converter products. This list will be the basis for this research.

Table 1. List of demands

	Need	Specification
Product	Material	ADC 12
	Appearance	There are no defects
	Weight	< 300 gr
	Wall thickness	Uniform (1,5-3 mm)
Production	Number of cavities	One piece
	Injection machine	Frech DAK 250-34
	Process cycle	Complete (*Clamping, Injection, Solidification, Ejection, Trimming*)

Product Prototype Development

The results of the second phase of this research include 3D product models, product designs and modifications, as seen in Figure 3, and temporary molds for prototype products, as seen in Figure 4. The temporary mold in question is only a core and cavity construction, while the mold base utilizes what is available in the Manufacturing Engineering Laboratory in Polman Bandung.

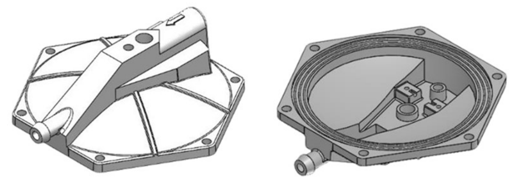


Figure 3. First product design

Next, a trial was carried out to produce a prototype product using a high-pressure die-casting machine available at the Foundry Engineering Laboratory in Polman Bandung—the prototype product results from the injection process, as seen in Figure 5.

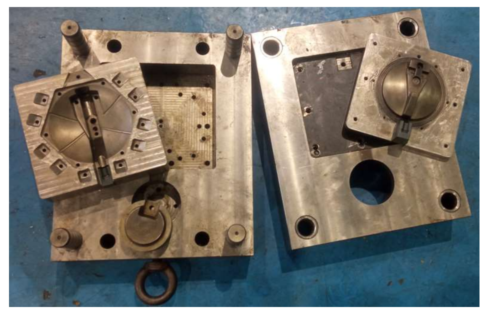


Figure 4. Temporary mold design

Figure 5. Casting prototype product (V1.0)

The prototype product has been formed perfectly during the HPDC process. ADC12 aluminum liquid fills the mold cavity completely. However, the product is not yet close to being finished. The product design still has a non-uniform wall thickness, so it can still be optimized.

Product Optimizations

Product design development is done to find the best solutions (see Figure 6). A Finite Element Analysis (FEA) simulation is carried out in SolidWorks simulation to ensure the product's strength, see Figure 7. The selected design is alternative-1; there is an increase in the stress that occurs in the product from 47.3 MPa to 72.9 MPa, but it is still within safe limits.

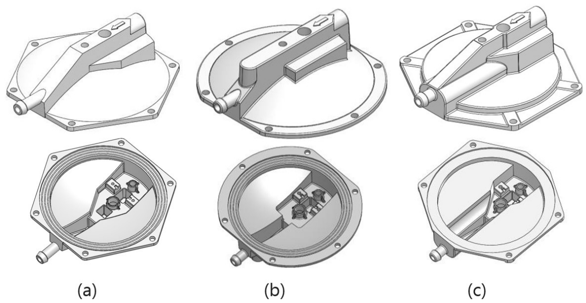


Figure 6. Alternative product design

The next step is to optimize the design of the selected product using the design study feature available in the engineering software. The design study parameters are high quality to find the optimal solution through many iterations and evaluate all results for all scenarios. Some of the set design variables are input rib thickness, input hole thickness, valve seat width, spring rib thickness, and spring hole thickness.

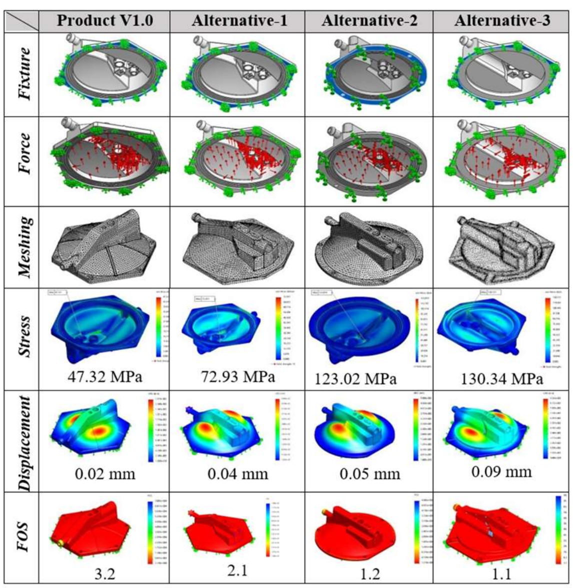


Figure 7. FEA analysis for product design

A vital optimization that must be focused on is reducing product weight, but not the strength aspect. The optimization results show that the product weight has decreased by 36%. However, the maximum stress has increased but does not exceed the specified safe limit of 100 MPa; see Table 2.

Table 2. Optimization Comparison Results

Parameter	Initial	Alternativ-1	Optimal
Massa [gr]	313.6	201.7	199.5
Stress [MPa]	47.3	72.9	73.8

Parameter Calculations

Tables 3 and 4 show the results of calculating design and injection parameters needed to control the success of product design and manufacturing processes with HPDC technology. Determining the value of this parameter refers to the recommendations of Buhler and Frech die caster.

Table 3. Design parameters

Parameter	Unit	Value
Cavity Volume	mm^3	71800
Overflow	mm^3	24850
Gate width (A)	mm	53
Runner width (B)	mm	32
Thickness gate (C)	mm	2
Thickness runner (D)	mm	10

Table 4. Injection parameter

Parameter	Unit	Value
Chamber diameter	mm	40
Filling ratio	%	30.48
Clamping force	kN	1092.7
Phase-1 length	mm	104
Phase-2 length	mm	226
Phase-1 speed	m/s	0.5
Phase-2 speed	m/s	2.6

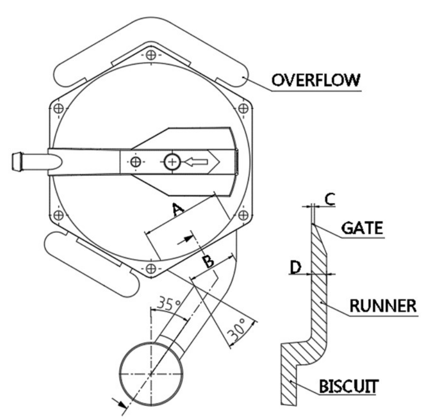


Figure 8. Product layout and gate system

After obtaining the design parameters, design the product layout system in the mold by determining the runner's shape and position, the number of gates, and the position and shape of the overflow. The layout and design of the channel system can be seen in **Error! Reference source not found.**.

CAE Flow Analysis

The results of the CAE Flow Analysis process, when entering injection and machine parameter data, as can be seen in Table 5, will obtain material flow conditions, filling temperature, flow velocity, and air trapped conditions.

Table 5. Simulation parameter

Parameter	Value
Product material	ADC12
Material temperature	730 °C
Mold material	1.2343
Mold Temperatur	300 °C
Shoot sleeve diameter	40 mm
Shoot sleeve length	340 mm
Phase-1 speed	0.5 m/s
Phase-2 speed	2.6 m/s
Phase-1 length	104 mm
Phase-2 length	226 mm

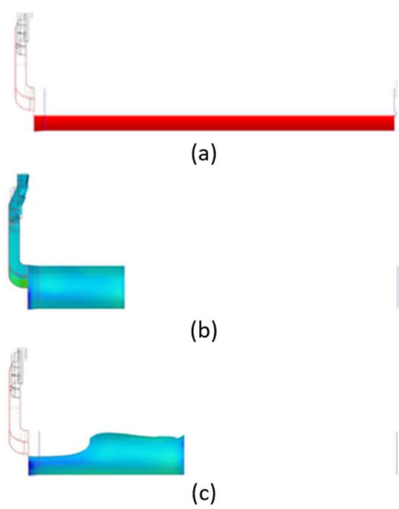


Figure 9. Material movement: (a) Filling Ratio 27.7% Phase; (b) Phase 1 at 0.5 m/s speed; (c) Phase 2 at 2.6 m/s speed

The simulation results show the movement of the injected material in the chamber, which moves laminarly; there is no trapped air (see Figure 9).

The simulation results show that the material temperature conditions during the mold cavity filling process are still liquid; this can be seen from the minimum temperature of 593.7 C (Hu et al., 2016), as seen in Figure 10. In general, the temperature distribution in the mold cavity is relatively even.

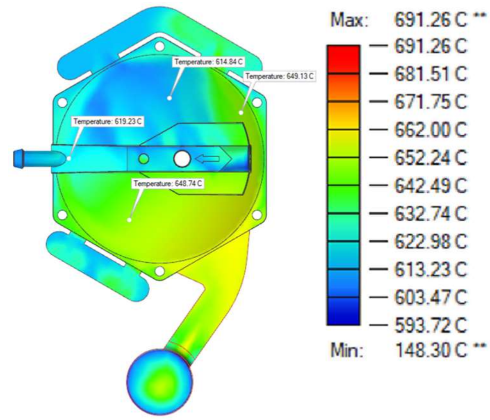


Figure 10. Filling temperature in the cavity

Figure 11 shows the material flow velocity at the gate. This condition is in accordance with those recommended by Buhler (1998), namely 20 m/s - 60 m/s.

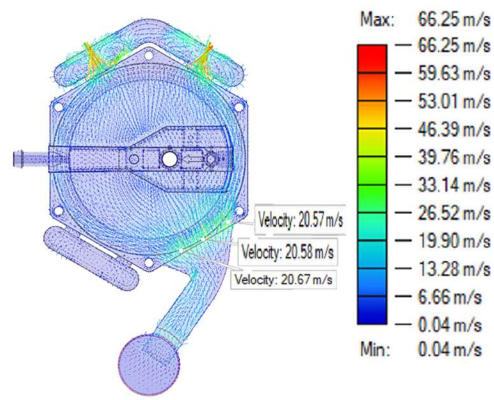


Figure 11. Material flow velocity in the gate

A necessary condition that needs to be known in the manufacturing process using HPDC technology is the condition of trapped air, which can cause product surface defects or porosity. The final air position condition is predicted to be in the overflow section, not the product. This result is good because it will not result in product defects, as seen in Figure 14.

Figure 13 shows conditions with a risk of porosity occurring in the product. This is predicted because this part has a greater thickness. A cooling system evenly distributed throughout the product can avoid this part.

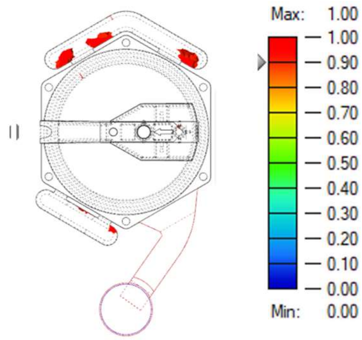


Figure 14. Air trap prediction in product

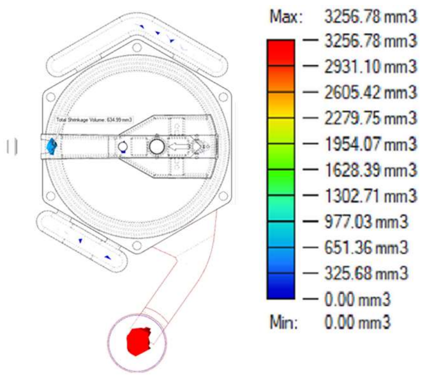


Figure 15. Total Shrinkage Volume

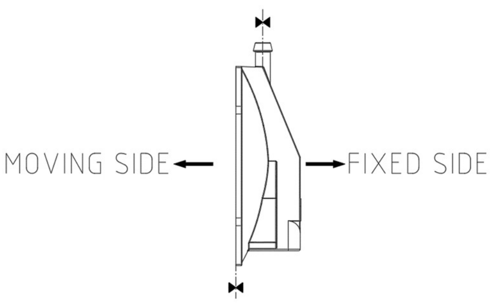


Figure 16. Parting line design

Table 6. Mold construction parameter

Parameter	Value
Min. insert dimension to cavity	50.8 mm
Min. slider-1 diameter	0.63 mm
Min. slider-2 diameter	22.96 mm
Total spring deflection	60 mm
Spring constant	1.6 N/mm

Mold Construction

Based on the CAE simulation results, which show conditions that are by expectations, the next step is to design the HPDC mold. Mold construction begins by determining the parting line position, as seen in **Error! Reference source not found.**. Ensure the product will be on the moving plate so it can be ejected.

Mold construction parameters are

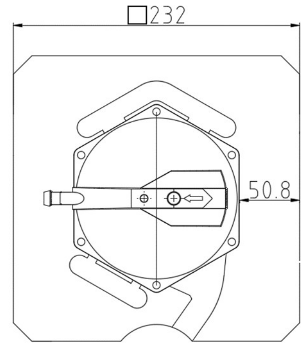


Figure 12. Insert cavity dimension

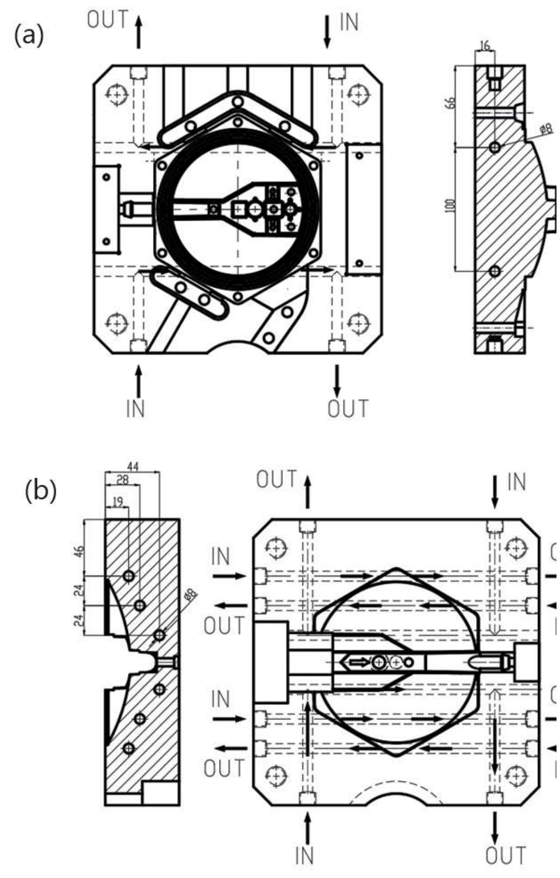


Figure 13. Cooling system: (a) insert core; (b) insert cavity

determined by referring to recommendations (Buhler, 1998) and the machine's clamping force requirements so that the aluminum material does not come out of the parting line gap during the injection process. Mold construction parameter data can be seen in **Error! Reference source not found.**.

Next, the insert dimensions are determined with insert material 1.2343, as said by (Wiedenegger et al., 2021), and a mold cooling system with a diameter of 8 mm, as seen in Figure 12 and **Error! Reference source not found.**. The cooling channel system was designed to make manufacturing easy using conventional machining processes.

The slider system design uses standard hydraulics from SMC type CHNF 20-72 for slider-1, as in Figure 17 (a), and CHSGFY 32-61 for slider-2, as in Figure 17 (b), in accordance with the minimum diameter required in **Error! Reference source not found.**.

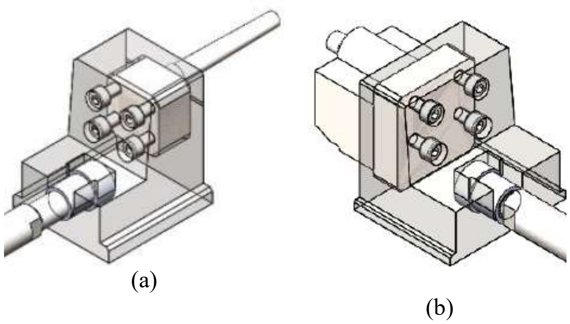


Figure 17. Slider constructions: (a) Slider-1; (b) Slider-2

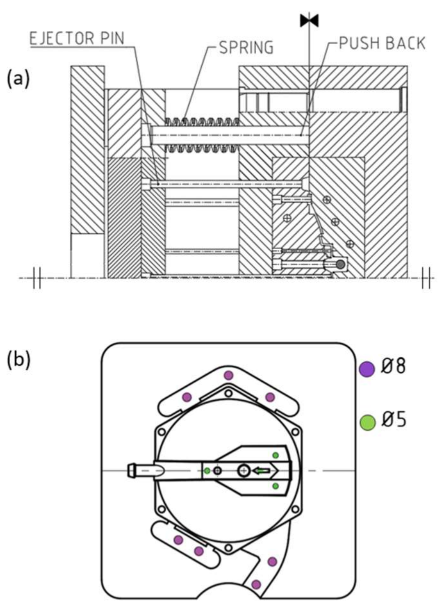


Figure 18. Ejection system: (a) Pushback system; (b) Pin Ejector layout

To facilitate the product dispensing process, it is necessary to design a product dispensing mechanism called an ejection system. The designed ejection system can be seen in **Error! Reference source not found.**. The position of the ejector is placed in such a way as to ensure that the product can be removed without damaging it. The ejector size is adjusted to the available location. This system is equipped with a pushback system for the reversing system; according to calculations, the spring selected is MISUMI spring type SWU 37-90.

IV. CONCLUSION

Casting product development and optimization, carried out using reverse engineering technology, has resulted in a product design.

The optimal top body converter, where the product weight has decreased by 36% and is still declared safe to accept loads according to its function. An illustration of the optimal product resulting from the development of the prototype can be seen in Figure 19.

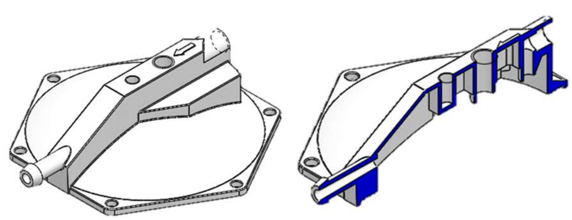
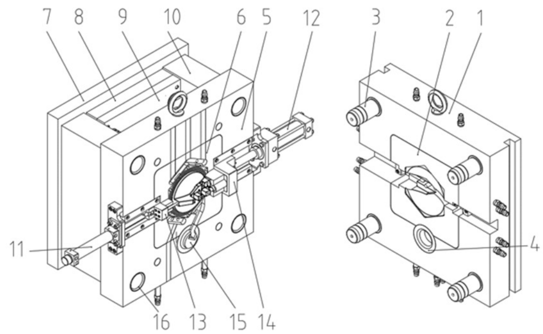


Figure 19. Optimal top-body converter



1. Cavity plate
2. Insert cavity
3. Guide bush
4. Spure
5. Core plate
6. Insert core
7. Bottom plate
8. Ejector plate
9. Retainer plate
10. Spacer
11. Hidrolik CHNF 20-72
12. Hidrolik CHSGFY 32-61
13. Slider-1
14. Slider-2
15. Riser
16. Guide bush

Figure 20. HPDC mold for top body converter

Apart from that, HPDC mold designs have been produced for optimal products. This mold is equipped with a slider system to form the product close to its final shape so that the manufacturing process after injection is not as much as the product resulting from the injection of the prototype product design, which can be seen in **Error! Reference source not found.**.

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