KIRPART

Filling Phase Optimization
with
MAGMASOFT® in HPDC

Çağatay Zadeoğlu

October 2024 - Frankfurt

Choice Of
Global OEM’s of the world ;
For Many Years...

For Many Years, we serve;

Global OEM's &TIER1's

with many models

Kırpart Product Groups

Thermostats

Water & Oil Pumps

Aluminium HPDC Parts

Electrification

FOUNDRY	MACHINING	ASSEMBLY

Each casting machine is equipped with its own holding furnace, automatic die lubrication, die heating-cooling device, jet cooling, vacuum unit and able to cast the parts weight from 50 gr. to 20 kg.

Melting Furnaces

- Shaft 2,0 Ton / Hr
- Shaft 2,0 Ton / Hr
- Shaft 1,0 Ton / Hr
- Crucible 0,25 Ton / Hr

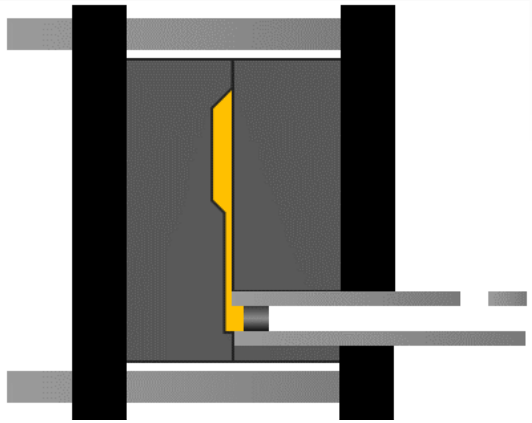
Press (Ton)	Pcs	Brand
400	1	Metal Press
550	2	Metal Press
550	1	Era Press
750	2	Colosio
1000	1	Colosio
1100	1	Metal Press
1100	2	Era Press
1600	1	Idra
1900	5	Idra
Total	**16**	

As with all casting techniques,
High Pressure Die Casting
also consists of two basic stages.

FILLING

1.Phase This is the phase where the liquid metal fills the chamber up to the gate level, ensuring no air remains in the chamber.

2.Phase This phase involves filling the part and overflow cavity within approximately 80ms.



SOLIDIFICATION

3.Phase This is the solidification stage where the liquid metal inside the mold is solidified under approximately 1000Bar pressure with the controlled heat transfer.

THE **MAGMA** APPROACH

OBJECTIVES

- Reduction of scrap rate.
- Reducing the number of redundant casting trials.
- Elimination of the trial and error method that creates waste.

VARIABLES

- 1st Phase Velocity
- 2nd Phase Velocity
- Switch Over

CRITERIA

- Prevent air entrapment in the chamber.
- Optimization of gate velocity in accordance with the PQ^2 diagram.
- Machine acceleration capability.

EFFICIENCY

- The part model was simplified by keeping the volume constant.
- Optimizations were carried out by dividing into segments.

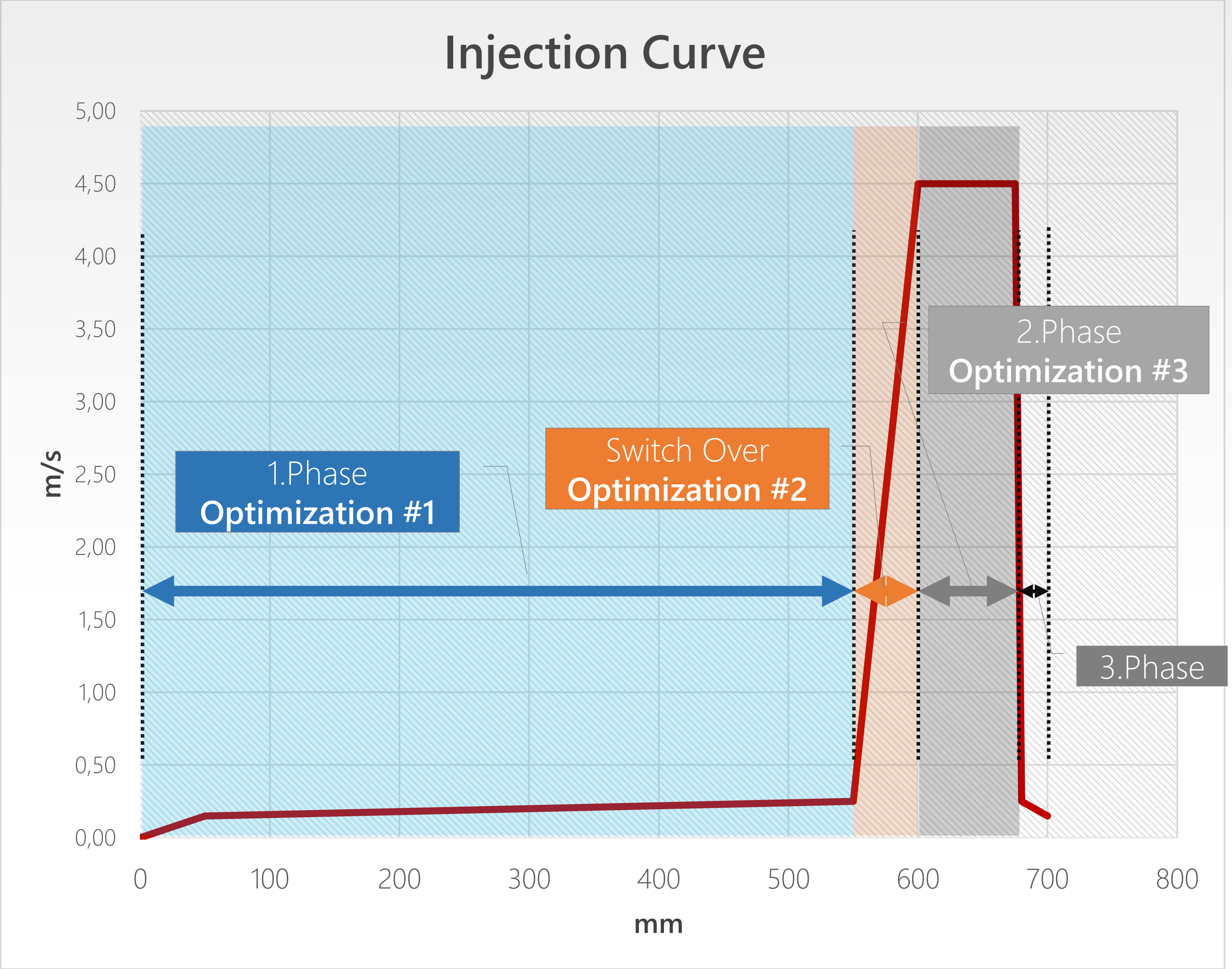
METHOD

- SOBOL METHOD
- PQ^2 Diagram
- Parametric Function

ACT & CHECK

- Correct result achieved in one go.
- Significant reduction in the number of casting trials.
- Reduction in scrap rates.

Optimization Chapters



Optimization #1 - 1.Phase

In Phase 1, the piston velocity accelerates starting from "0" and then continues at an accelerated or constant velocity value.

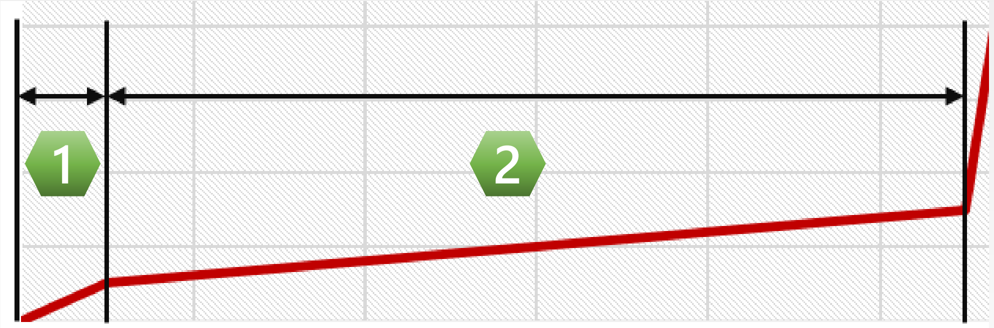
Optimization #2 – Switch Over

Refers to the acceleration between 1st phase and 2nd phase. In the optimization, the position of this movement and its compatibility with the machine are examined.

Optimization #3 – 2.Phase

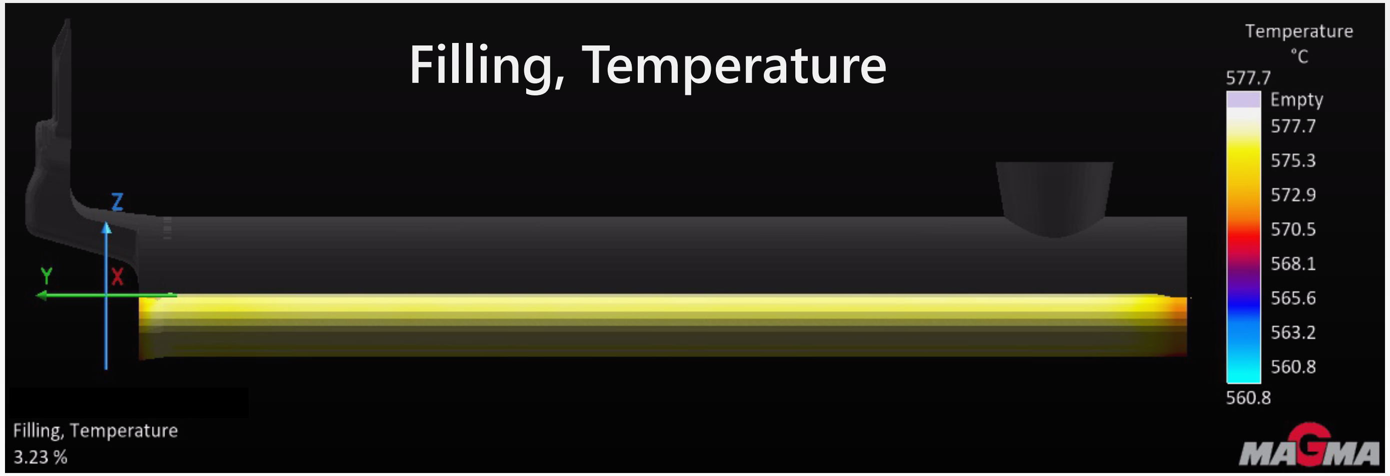
2nd Phase velocity is achieved in this optimization. With the help of the PQ^2 diagram, the machine capability is questioned in that velocity value.

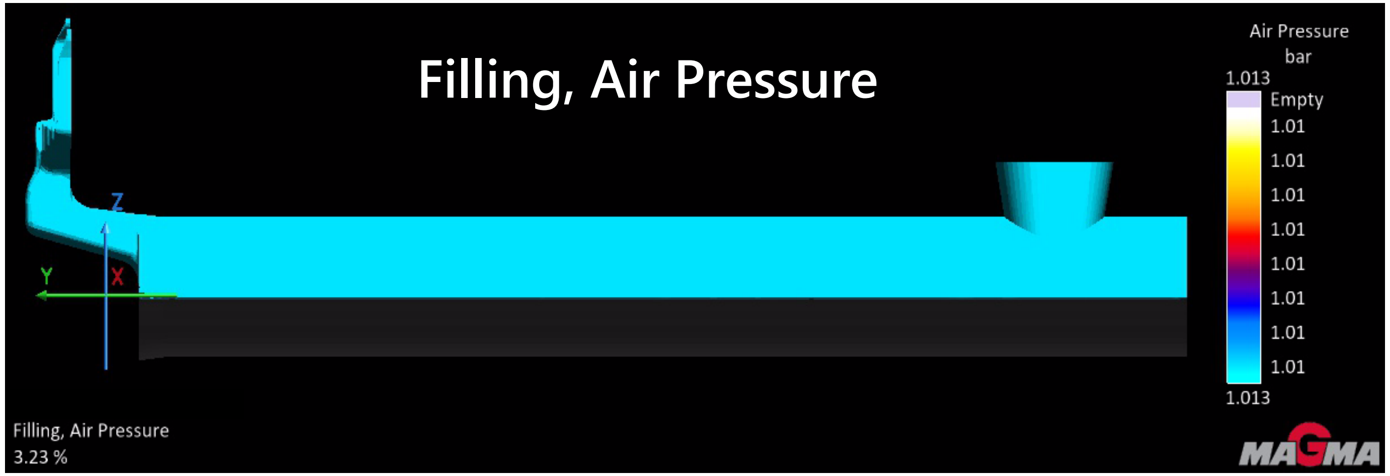
Optimization #1 – 1st Phase



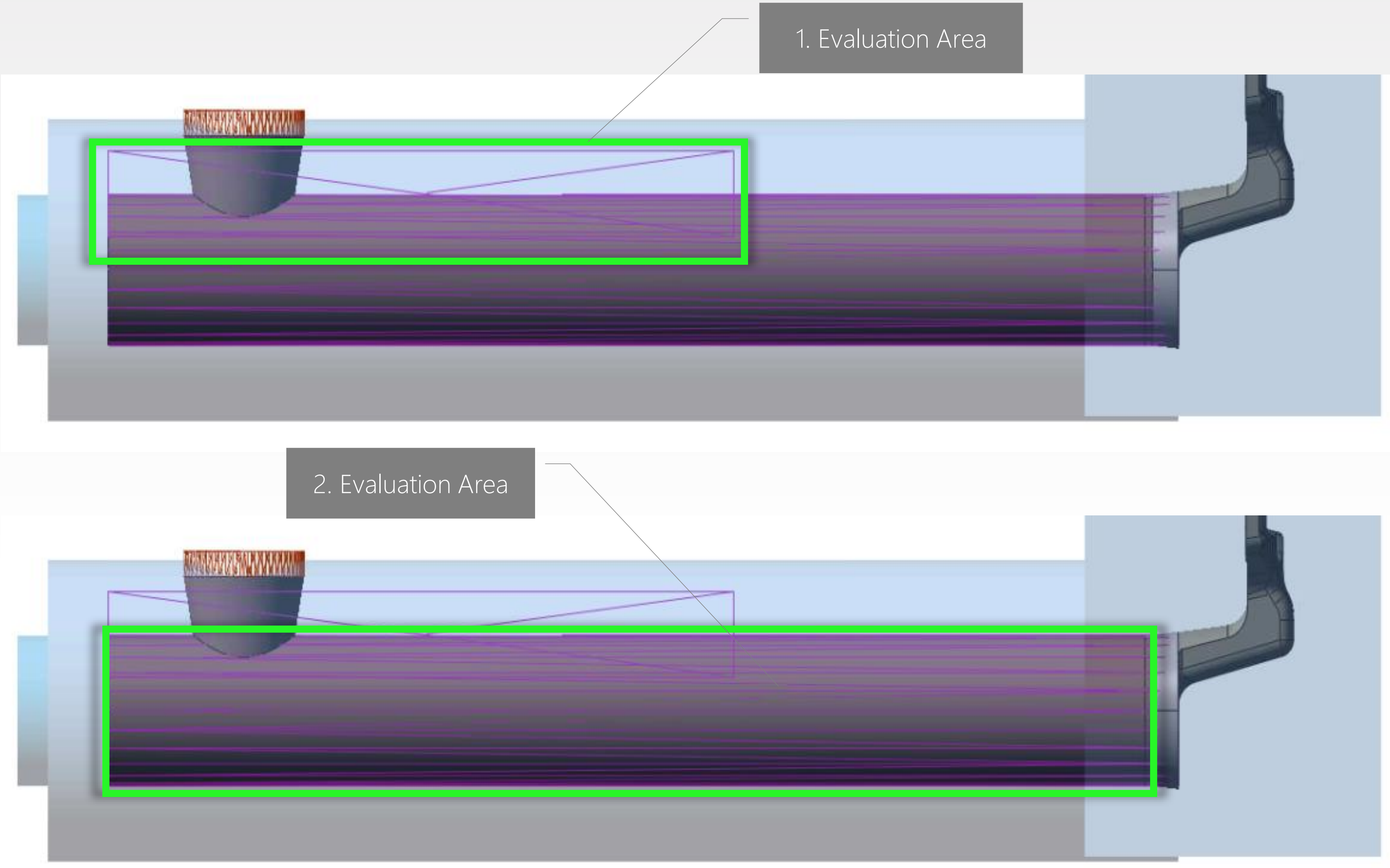
Phase 1 consists of two main step.

In the first step; the piston will overcome the frictional force, gain acceleration and start its first movement. Acceleration at this stage can cause an undesired wave motion in the liquid metal.
In the second step; the piston, which performs its first movement, should move with the metal wave it creates in front of it and move at a velocity or acceleration that will not cause air entrapment in the chamber.





Optimization #1 – 1st Phase



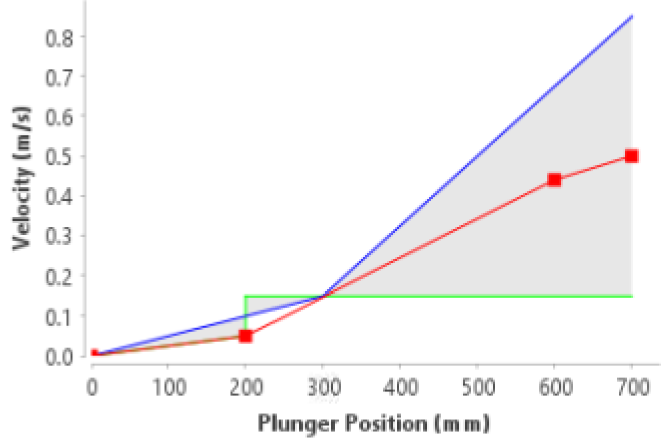
Two different 'Evaluation Areas' are defined for the optimization setup.

In the **1st Evaluation Area**, velocity differences are analyzed.

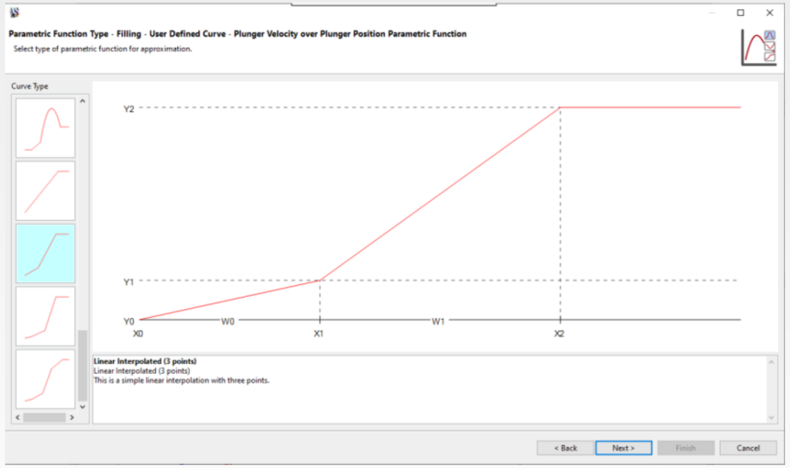
In the **2nd Evaluation Area**, air entrapment is also analyzed together with the velocity results.

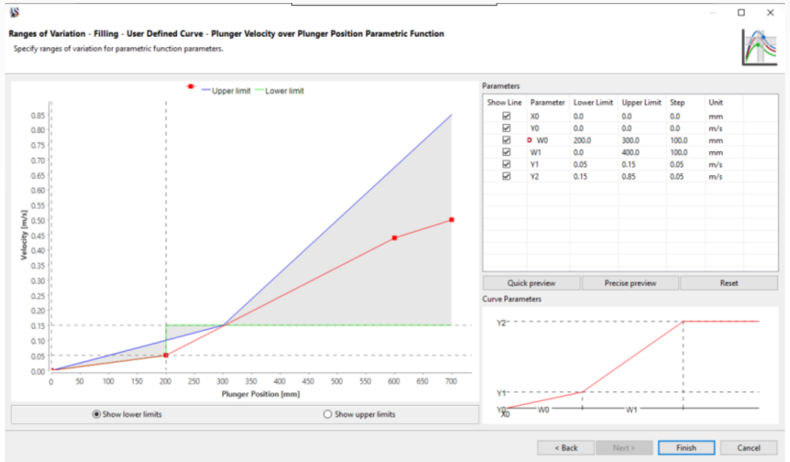
Optimization #1 – 1st Phase

Design Variables

Design Variable	Parametric Function
☑ Filling - User Defined Curve - Plunger Velocity over Plunger Position Parametric Function	

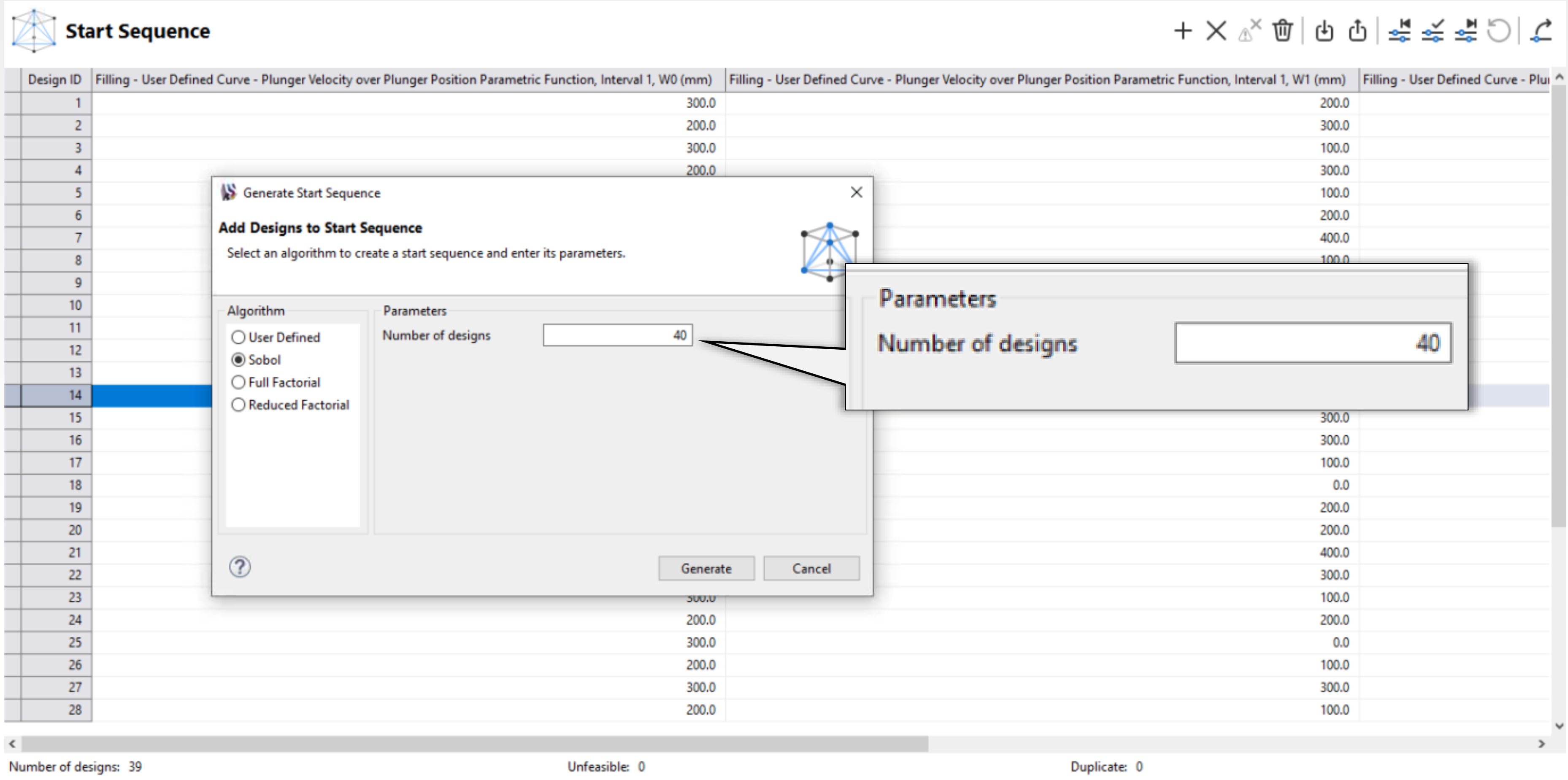
Parametric Function Parameter, Interval 1	Lower Limit	Upper Limit	Step
☑ X0	0.0	0.0	0.0
☑ Y0	0.0	0.0	0.0
☑ W0	200.0	300.0	100.0
☑ W1	0.0	400.0	100.0
☑ Y1	0.05	0.15	0.05
☑ Y2	0.15	0.85	0.05





In 1st Phase Optimization, "***parametric function***" was used to determine the wave by the momentum of the piston and the subsequent acceleration or constant velocity values. A total of 450 design examples were created according to the variables entered.

Optimization #1 – 1st Phase



450 different design examples were reduced to 40 designs using the *Sobol Method*.

Optimization #1 – 1st Phase

Objectives

	Name	Type	Value	Expression
☑	Air	Minimize		{Cycle 1/Filling/Air/25.0 %/Avg/Cast Alloy Class, Evaluation Area ID 1}
☑	Velocity	Minimize		{Cycle 1/Filling/Velocity/Absolute Velocity/Max/Cast Alloy Class, Evaluation Area ID 2}
☑	Temperature	Minimize		690-{Cycle 1/Filling/Temperature/25.0 %/Avg/Cast Alloy Class, Evaluation Area ID 1}
☑	VOF	Minimize		{Cycle 1/Filling/VOF/Max Free Surface of Cast Alloy Class, Evaluation Area ID 1}
☑	Velocity1	Minimize		{Cycle 1/Filling/Velocity/25.0 %/Velocity Y/Max Diff/Cast Alloy Class, Evaluation Area ID 1}
☑	Velocity2	Minimize		{Cycle 1/Filling/Velocity/Velocity Y/Normalized Average Direction of Cast Alloy Class, Evaluation Area ID 1}

Air

The objective is to minimize the amount of air entrapment in the chamber at the 25% of the filling stage.

Temperature

The objective is to minimize temperature changes in the liquid metal.

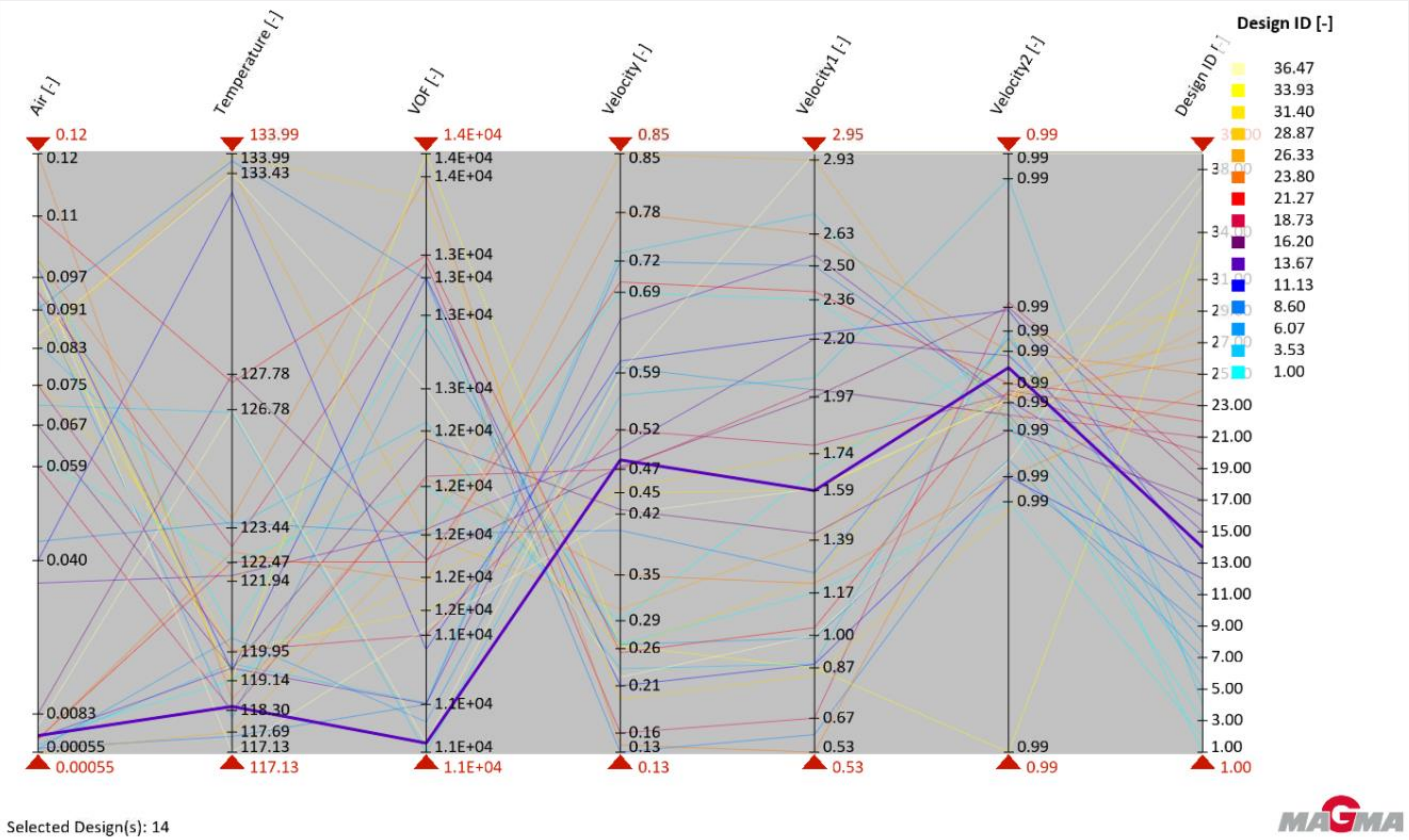
VOF

The objective is to minimize the amount of free surface of the liquid metal.

Velocity

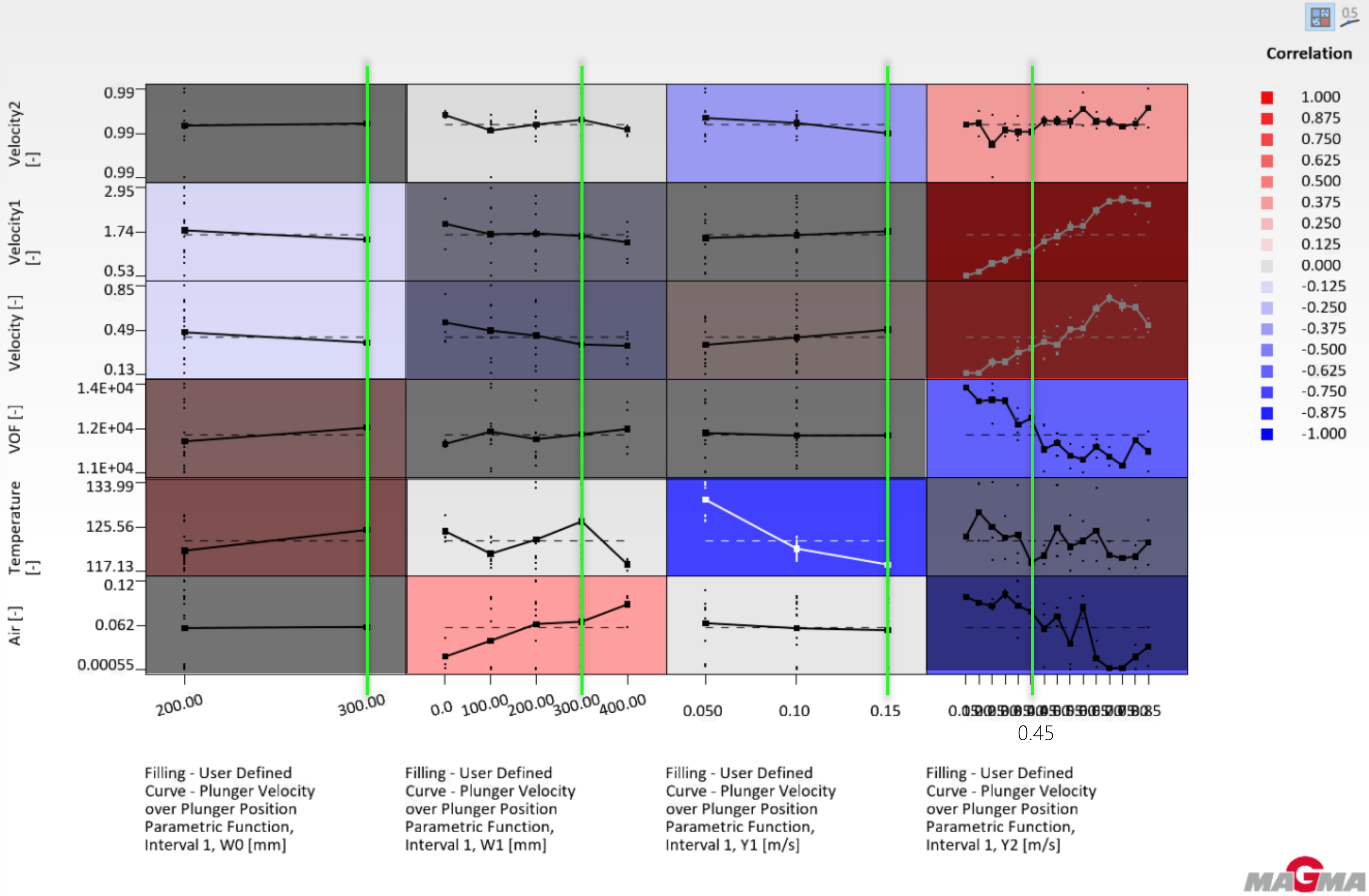
The objective is to minimize the difference in metal velocity along the Y-axis.

Optimization #1 – 1st Phase



As a result of the optimization, the most suitable values were obtained in the **14th design**.

Optimization #1 – 1st Phase

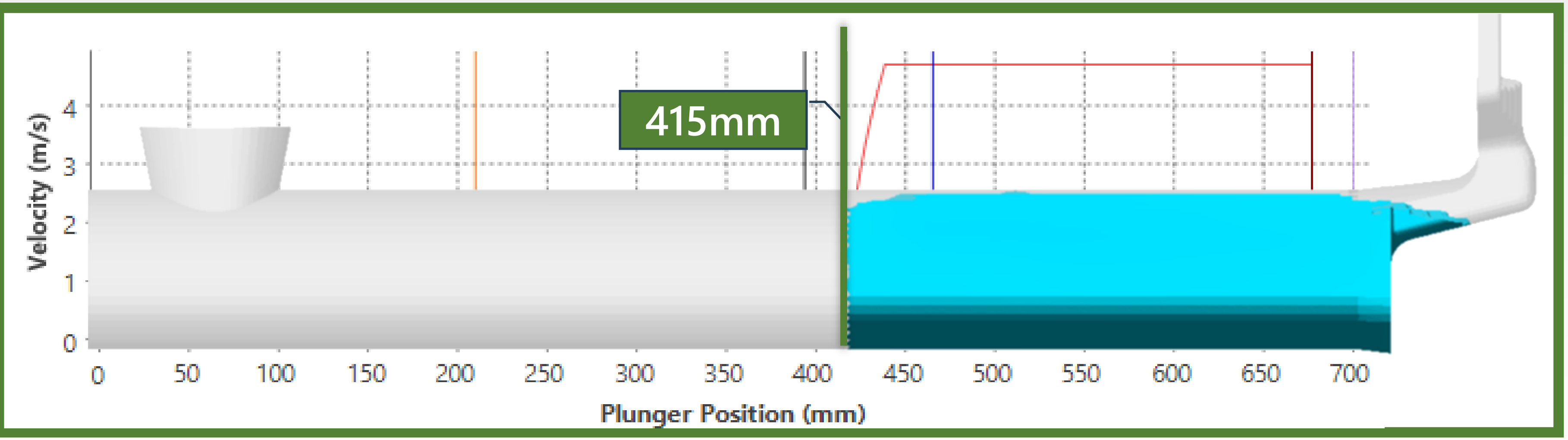


In the "Main Effect Matrix" perspective, the outputs for each objective entered are shown in a table depending on the variables.

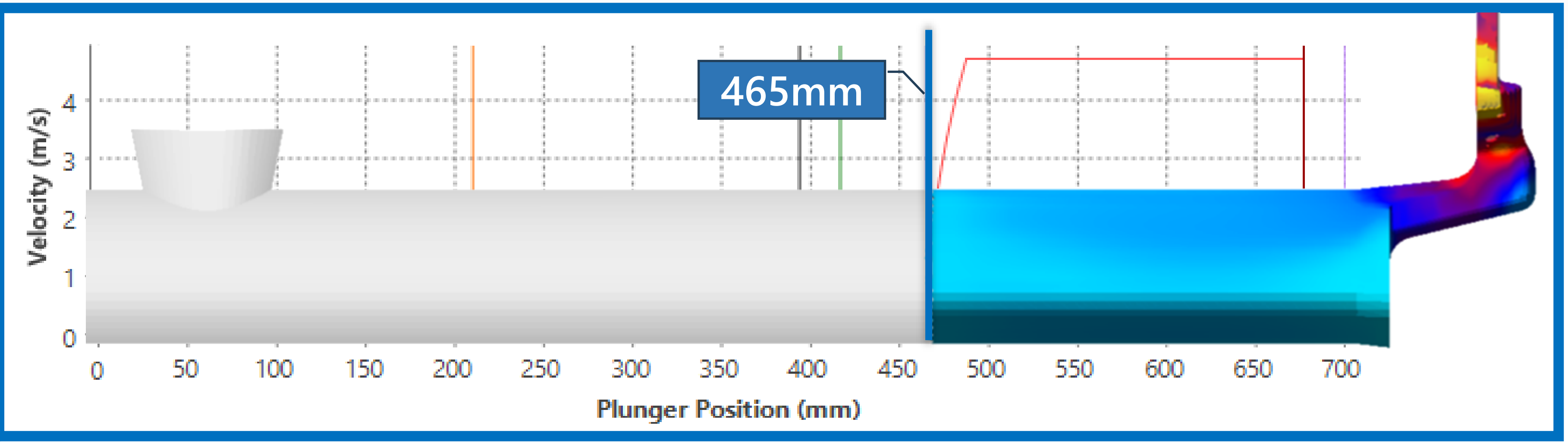
Each relevant objective is examined in the table depending on the corresponding variable.

Optimization #2 – Switch Over

Chamber Full



Metal At Gate



Between 1st Phase and 2nd Phase, there is a transition area called "switch over" which depends on the machine capabilities.

Except for extreme examples, this acceleration distance should be between the *"metal at gate"* or *"chamber full"* positions depending on the part character and runner design.

Optimization #2 – Switch Over

Design Variables

	Design Variable	Lower Limit (mm)	Upper Limit (mm)	Step (mm)
☑	Filling - Acceleration Phase - Start - At Plunger Position	415.0	465.0	5.0

In the **switch over optimization**, design variables were selected between 415mm (chamber full) and 465mm (metal at gate) with 5mm steps.

A total of 10 different designs were created and the simulation was run.

Optimization #2 – Switch Over

Objectives

	Name	Type	Value	Expression
☑	Air	Minimize		{Cycle 1/Filling/Air/from 0.0 % to 100.0 % every 0.1 %/Max/Runner ID 1}
☑	Velocity	Minimize		{Cycle 1/Filling/Velocity/Velocity Z/Normalized Average Direction of Runner ID 1}
☑	VOF	Minimize		{Cycle 1/Filling/VOF/Max Free Surface of Runner ID 1}
☑	Air Contact	Minimize		{Cycle 1/Filling/Air Contact/End of Filling/Min/Runner ID 1}

Air

The objective is to minimize the amount of air entrapment in the chamber at the 100% of the filling stage.

Velocity

The objective is to minimize the velocity difference in the Z axis in metal velocity.

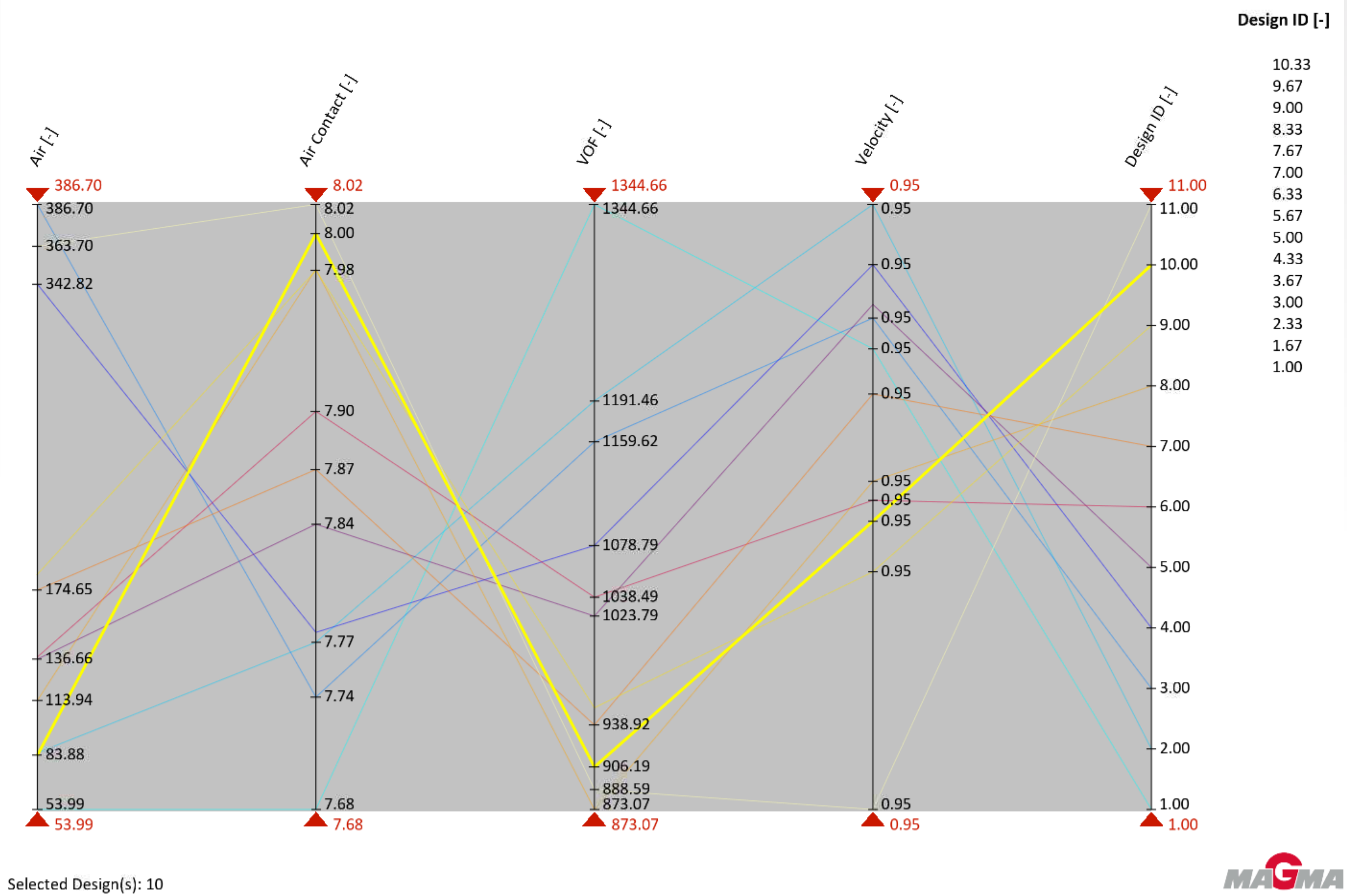
VOF

The objective is to minimize the amount of free surface of the liquid metal.

Air Contact

The objective is to minimizing the air contact surface of liquid metal.

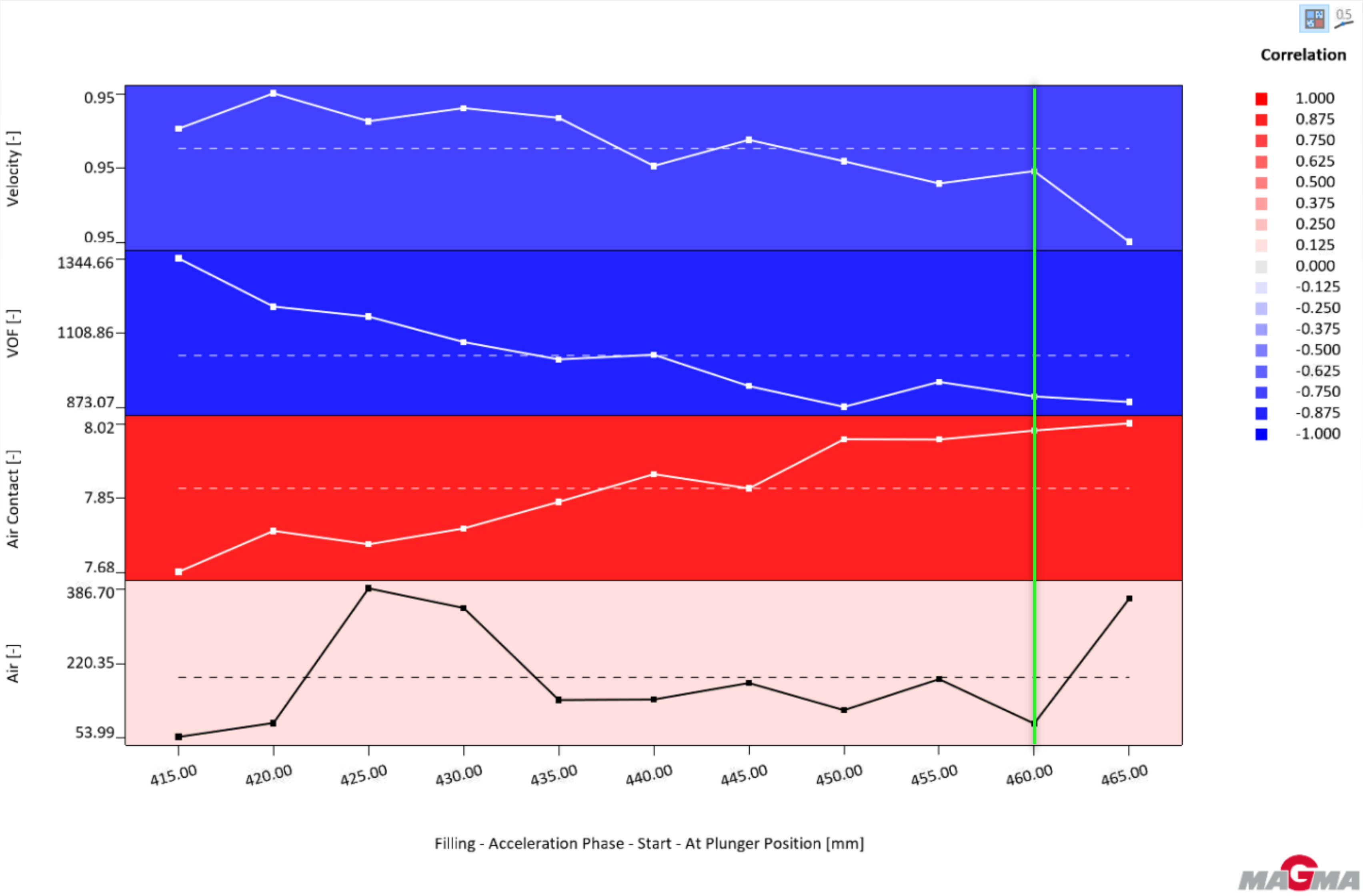
Optimization #2 – Switch Over



As a result of the optimization, the most suitable values were obtained in the **10th design**.

Although the 'Air Contact' results were selected at high values, the maximum and minimum values of 'Air Contact' do not have a wide range as seen in the graph.

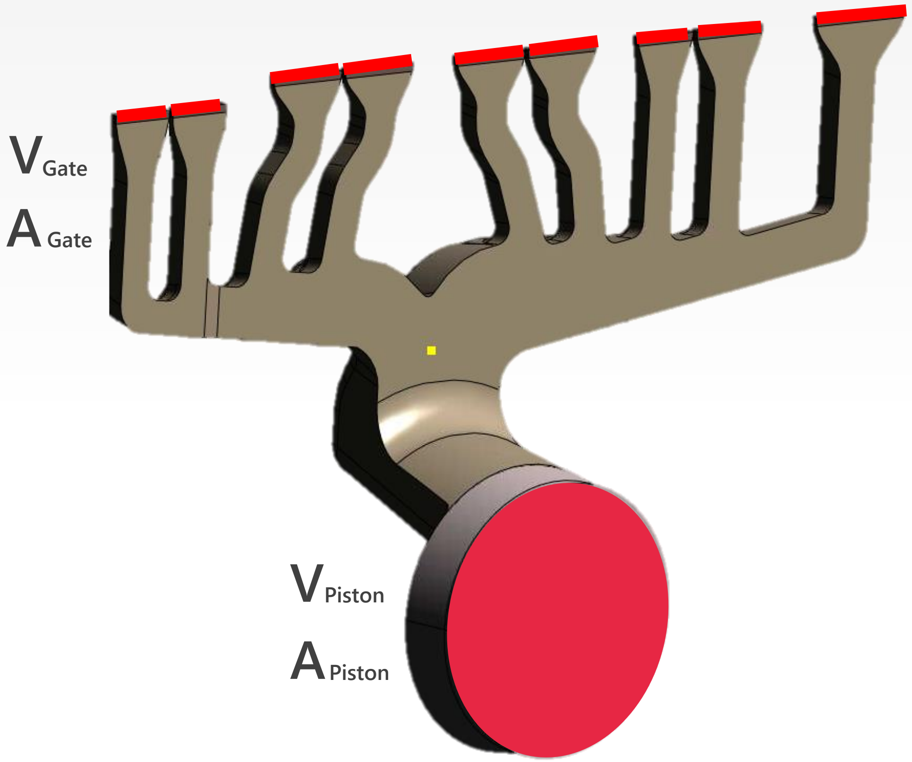
Optimization #2 – Switch Over



As a result of the optimization, the most suitable values were obtained in the **10th design**.

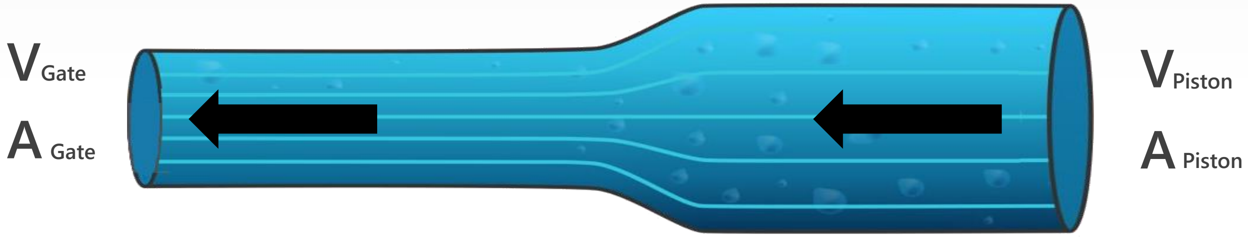
Optimization #3 – 2nd Phase

$$V_{Piston} \times A_{Piston} = V_{Gate} \times A_{Gate}$$



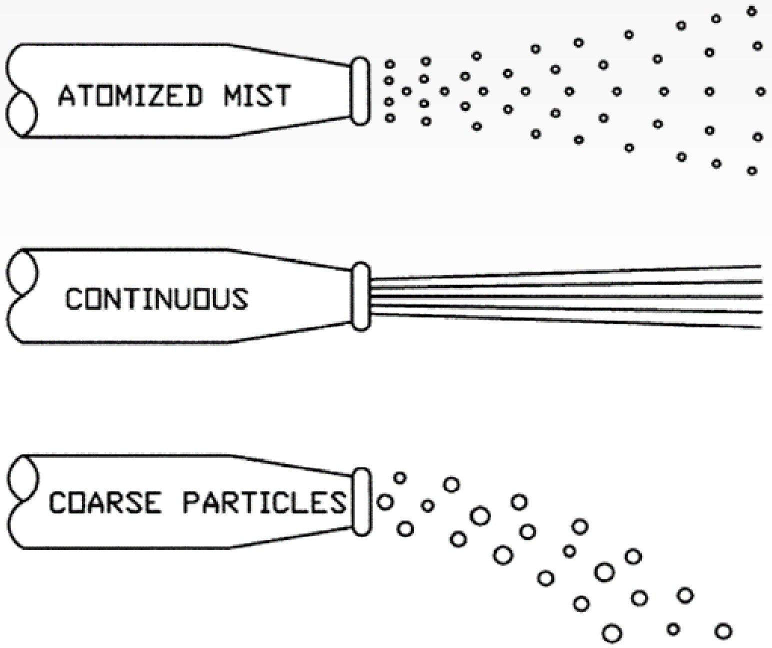
Bernoulli Principle

Equation of Continuity



Optimization #3 – 2nd Phase

$$V_{Piston} \times A_{Piston} = V_{Gate} \times A_{Gate}$$



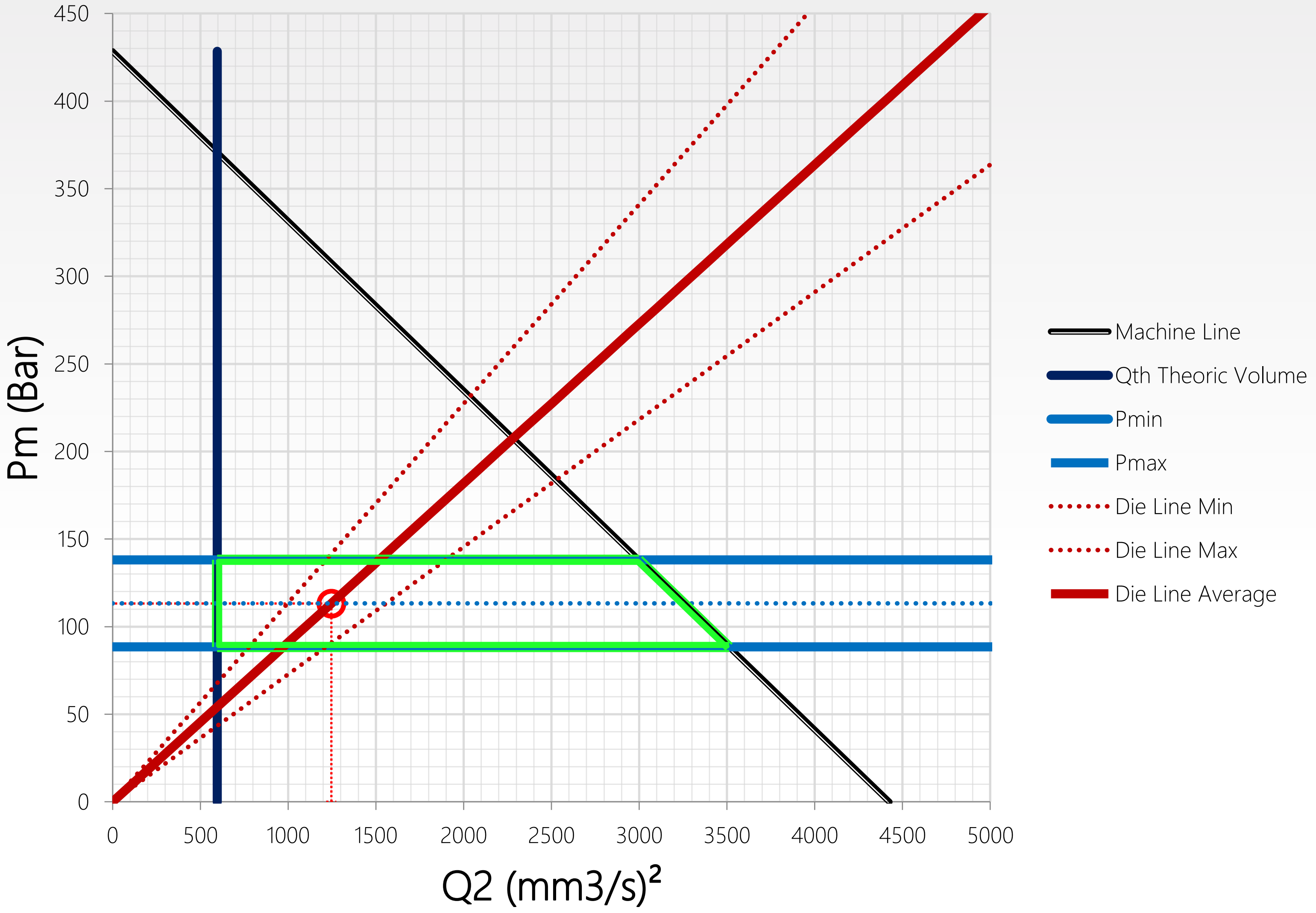
$$V_{Gate} = 35m/s - 50m/s$$

$$V_{PMin} = 35m/s \times 8{,}21cm^2 / 63{,}62cm^2$$

$$V_{PMax} = 50m/s \times 8{,}21cm^2 / 63{,}62cm^2$$

$$V_{Piston} = 4{,}5 – 6{,}5\ m/s$$

Optimization #3 – 2^{nd} Phase



PQ² Diagram Shows that the desired 2^{nd} phase velocity is within the capabilities of the machine. As can be seen in the diagram on the right, the calculated 2^{nd} phase velocity is seen in the green frame. Therefore, the machine to be produced is capable of reaching the maximum speed we have calculated.

Optimization #3 – 2nd Phase

Design Variables

	Design Variable	Lower Limit (m/s)	Upper Limit (m/s)	Step (m/s)
☑	Filling - Second Phase - Velocity	4.5	6.5	0.5

In Phase 2 Optimization, the calculated min - max velocity values of 4.5m/s and 6.5m/s were entered.

A total of 5 different simulations were run by setting the step as 0.5m/s.

Optimization #3 – 2nd Phase

Objectives

	Name	Type	Value	Expression
☑	Smooth Filling	Minimize		{Cycle 1/Filling/VOF/Max Free Surface of Cast Alloy Class}
☑	Reduce Gate Velocities	Minimize		{Cycle 1/Filling/Velocity/Absolute Velocity/Max/Gate All IDs}
☑	Avoid Misrun	Maximize		{Cycle 1/Filling/Temperature/Min/Casting All IDs}
☑	Hot Spot FSTime	Minimize		{Cycle 1/Solidification & Cooling until Eject/Hot Spot FSTime/Volume/Casting ID 1}
☑	Air Pressure	Minimize		{Cycle 1/Filling/Air Pressure/End of Filling/Avg/Casting ID 1}

Air Pressure

The objective is to keep the amount of air entrapment in the casting to a minimum.

Hot Spot FS Time

The objective is reducing shrinkage by increasing the temperature of the kinetic energy inside the mold.

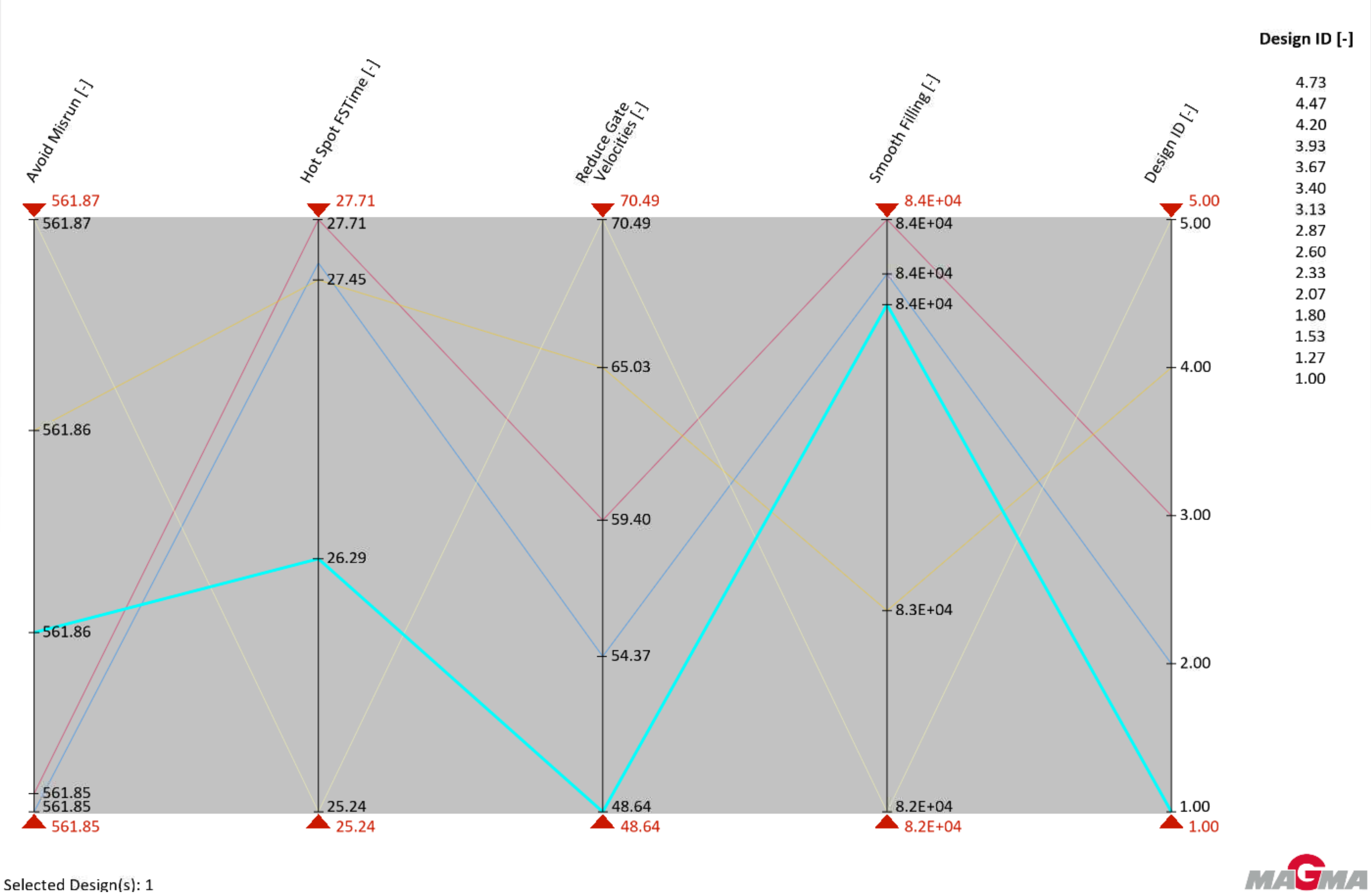
Reduce Gate Vel.

The objective is elimination of maximum velocity occurring at gate points.

Avoid Misrun

The objective is minimum turbulence formation in the flowing liquid metal.

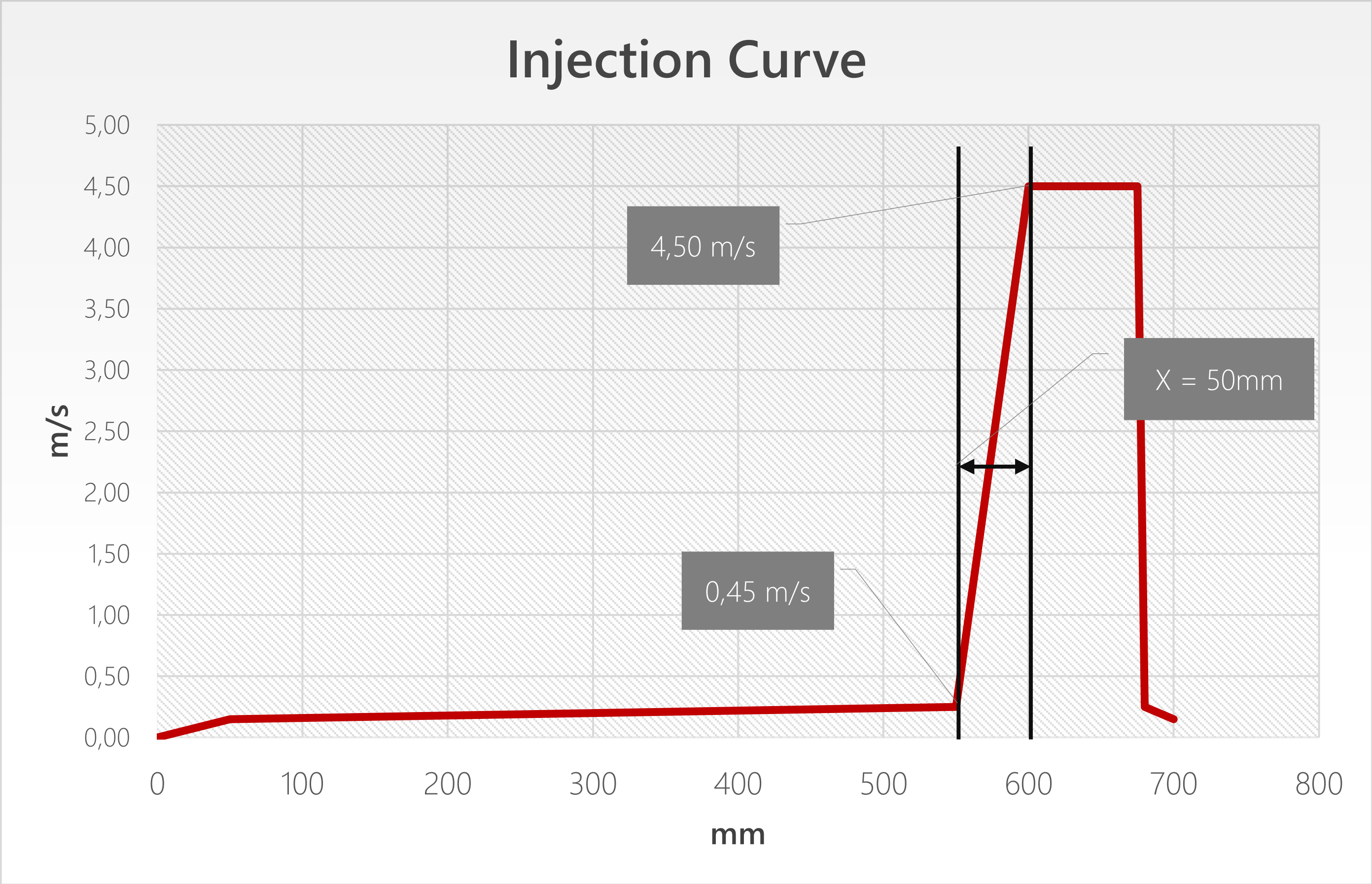
Optimization #3 – 2nd Phase



As a result of the optimization, the most suitable values were obtained in the 1st design.

When we carried out our examination from the perspective of parallel coordinates, design 1, which is below the maximum gate velocity and where targets such as turbulence hot spot are at acceptable levels, was selected.

Optimization #3 – 2nd Phase



The piston velocity must increase from V_1 to V_2 within a distance of X. Therefore, the machine must provide this capability.

The acceleration calculated from the following "*equation of motion without time formula*" must be smaller than the maximum acceleration of the machine.

$$V^2 = V_0^2 + 2\alpha x$$

$$\alpha = \frac{V_2^2 - V_1^2}{2x} = \frac{(4,5)^2 + (0,45)^2}{2 \times 0,05}$$

$$\alpha = 200.475\ m/s^2 < \alpha_{Machine} = 500\ m/s^2$$

Results

Optimization #1 - 1.Phase
→ **14th Design**

Optimization #2 – Switch Over
→ **10th Design**

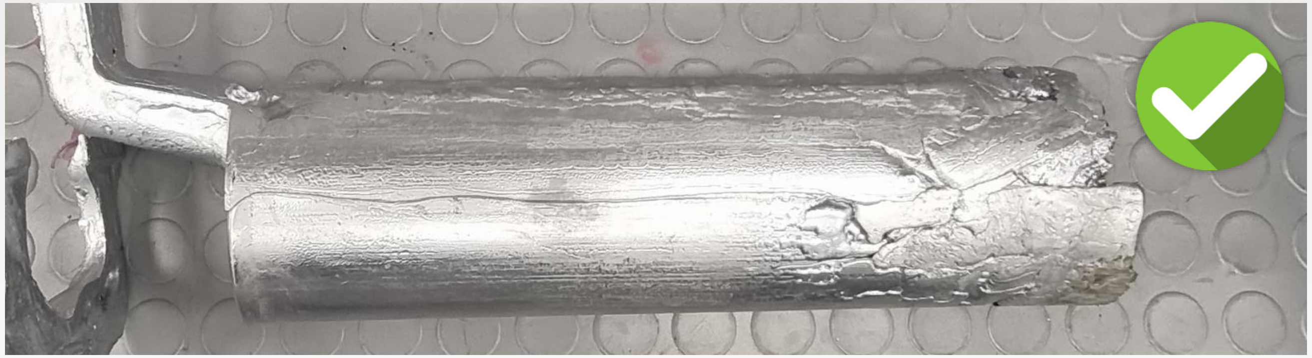
Optimization #3 – 2.Phase
→ **1st Design**

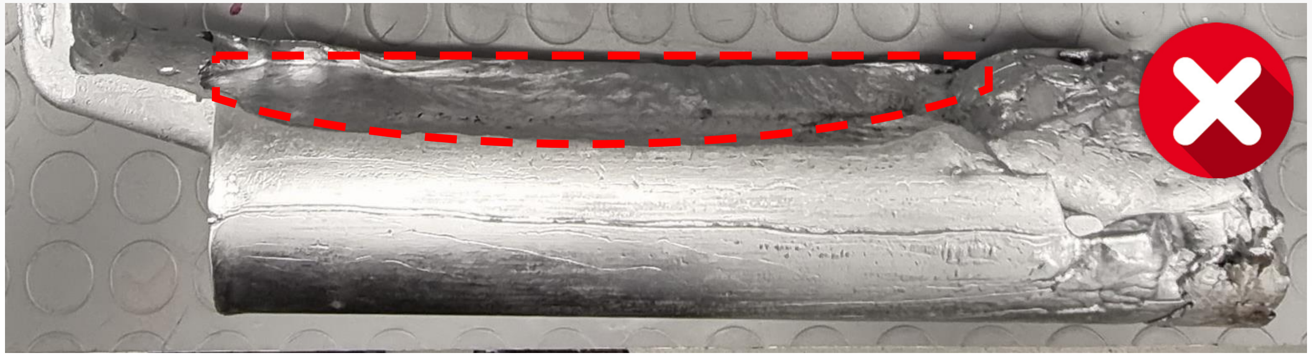
On the side air pressure results were obtained by combining three different optimizations.

At the top, the filling result of the combined designs does not show any air entrapment. This is a result that we always aim for.

Clearly, we can see undesired air entrapment result at the bottom. A large amount of air is trapped in the last stage of the chamber filling.

Samples



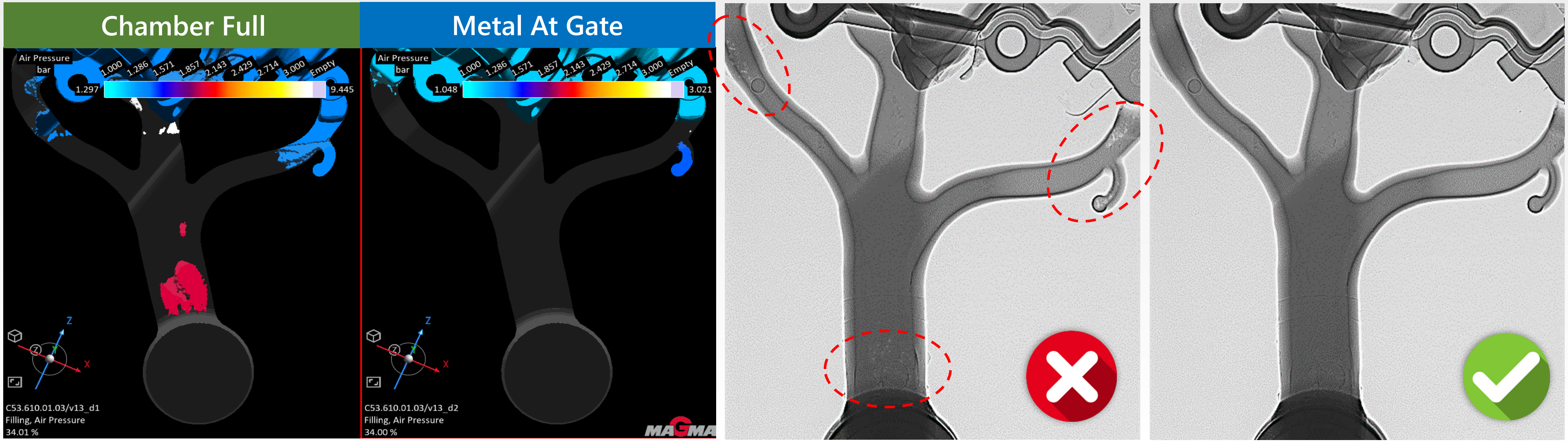


In the images above, we can see the results obtained in the previous slide with the "die filling test".

The first image does not show any air entrapment.

However, in the other image, there is a high amount of air entrapment in the marked region, which is also seen in the simulation result.

Samples



The filling results of two different simulations with both chamber full and metal at gate points are shown above.

Chamber full → In this example, at the switch over with chamber full, air entrapment is observed in the main runner as shown in the X-Ray results on the side.

Metal at gate → In the other result, 'metal at gate', no air entrapment was observed in the runner. X-Ray results also support the simulation.

Thank You

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