

# Searching for the optimal velocity of the piston in an HPDC process

3D optimization study of the velocity profile during first phase shot sleeve process

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## The question

High pressure die casting processes are one of the most complex phenomena in the foundry world due to the high number of physical process involved simultaneously and their strict net of relations. It becomes hard for the technician to change just a single aspect of the process without the risk to be involved in many other secondary changes that affect the final product, sometimes in a distinctive matter.

A quite interesting example involving simple geometries is the focus of the actual paper, unified with the searching of its optimal compromise between all the physical parameters: the run of the piston in the hot chamber to inject the metal inside the mould.

Nowadays HPDC machines are become like small computers, where the foundry user is able to setup the machine by customizing every its single parameter and to have a very high control over them, from the temperature of the chamber up to the motion of the piston during the time.

This gained "freedom" brings with it some new and not trivial problems: how to manage this freedom? How to move inside all these parameters and combine them together to have an excellent product?

The human knowledge is of course the primary help in this choice and, for sure, this added freedom open the doors to build virtually optimal products. In fact, how can we exclude that, among the all combinations of the parameters, there is one that provide us a perfect product in a fast time and at cheaper costs? This is the goal of our task.

Going back to our example of the motion of the piston in the hot chamber, we have a not easy task: if we move the piston as fast as possible to reduce the cooling of the metal, the process time, and the oxidation, we will face with a high surface breaking and air entrainment; on contrary, if we keep a slow first phase velocity (the actual solution) we will minimize the wave breaking but the process time will be longer with a higher pouring temperature and costs.

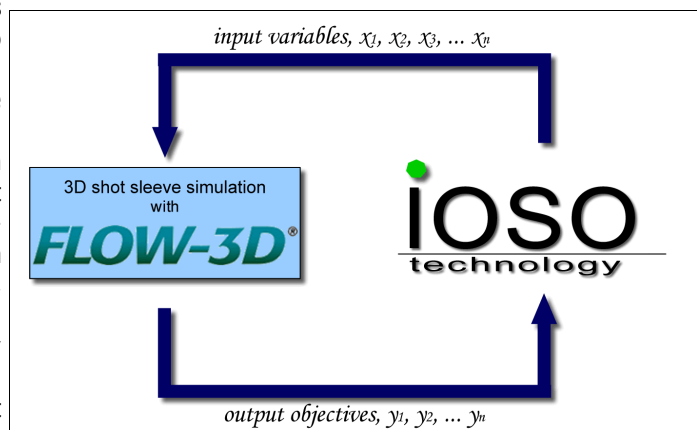
Another complex phenomena to take into account during the motion of the piston is the formation and travelling of waves, that moves along the chamber, reflecting, and summing up in many different ways.

To solve these problems different solutions exist, some with more simplifications, some with less, but all using mono-dimensional or at least bi-dimensional approaches that tries to solve the motion of the waves travelling inside the chamber in an analytical way, keep them unbreaking and in-phase with the piston. One of the most interesting study on this topic is reported in the paper "Minimizing air entrainment in a shot sleeve during slow-shot phase", by Michael Barkhudarov ([http://www.flow3d.com/resources/tech\\_paper/res\\_tp\\_casting.html](http://www.flow3d.com/resources/tech_paper/res_tp_casting.html)).

But, with a three-dimensional approach, things can be different.

## FLOW-3D and IOSO NM

The analysis reported in this document wants to show a very fast and simple solution to afford general problems where the design variables are many, as many are the objectives to evaluate, and the user want to find quickly the optimal setup. It is based on the coupled use of two software, each of that represent the excellence in its field: FLOW-3D, a fluid-dynamic solver, and IOSO NM, a Russian numerical optimization technology, multi-parametric and multi-objective. Our intent will be to find the best velocity profile for the piston (during the first phase) in order to achieve the goal of a short process time and – in the same time – minimize the surface breaking and air entrained.



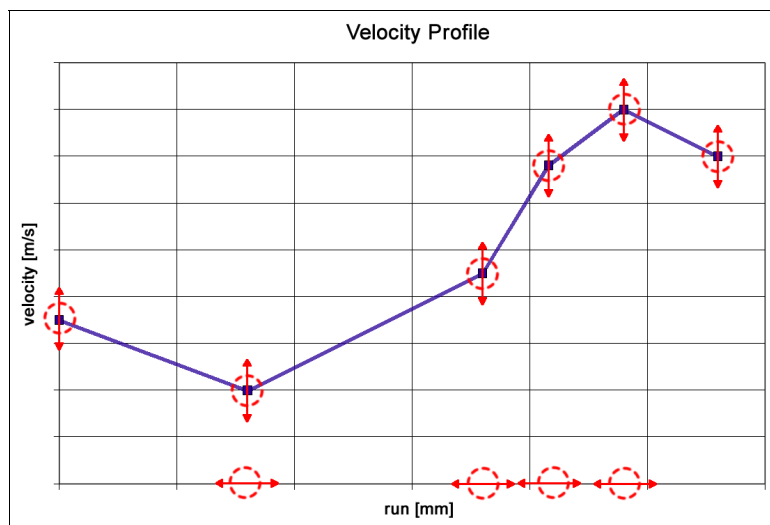
The workflow to execute is quite simple: IOSO choose the velocity profile to give to the piston, FLOW-3D simulate the complete 3D and turbulent metal behaviour and extract some “quality” parameters related to the shot, IOSO interpret the results and re-run the simulation trying to find the best velocity profile in order to reach all the given goals (**figure 1**).

### Optimization setup

Thanks to Buhler consultancy - Swiss company, global specialist in the supply of plants and services for processing grain and food as well as in casting machine manufacturers - a reference HPDC real machine has been chosen, filled with an average level of metal, and taking as end for the analysis the transition time between the first phase and second phase run.

The reference machine has the ability to be setup by the user programming up to 20 points of “run” vs “velocity”, even if for the first phase stage only 4 points are commonly used.

To let IOSO work under the best freedom conditions we have chosen to give to it as free parameters 6 run points and the relative velocity values for a total of 10 design variables totally independent (the initial and final run, in fact, are given)(**figure 2**).

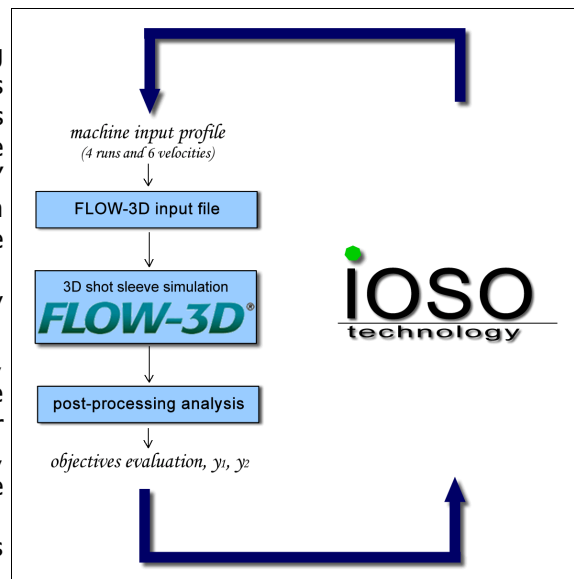


The choice of the objectives should be something minimal but enough to adequately describe the physics and the quality of the filling. Two concurrent objectives have been chosen: minimize the time required for the first phase stage, and minimize the “Air Entrainment” variable given by FLOW-3D during the whole simulation and useful index for the turbulence and surface breaking of the metal.

Just notice that the two objectives are not only equally important but also reciprocally contrasting.

IOSO optimal solution will then be not a single solution, but a curve of solutions (Pareto curve) giving all the best compromises between first phase time and air entrained. The user will have to choose, in the end, following his experience, the point that satisfies at the best his needs.

The final workflow map gains some intermediate steps and becomes the one of **figure 3**.

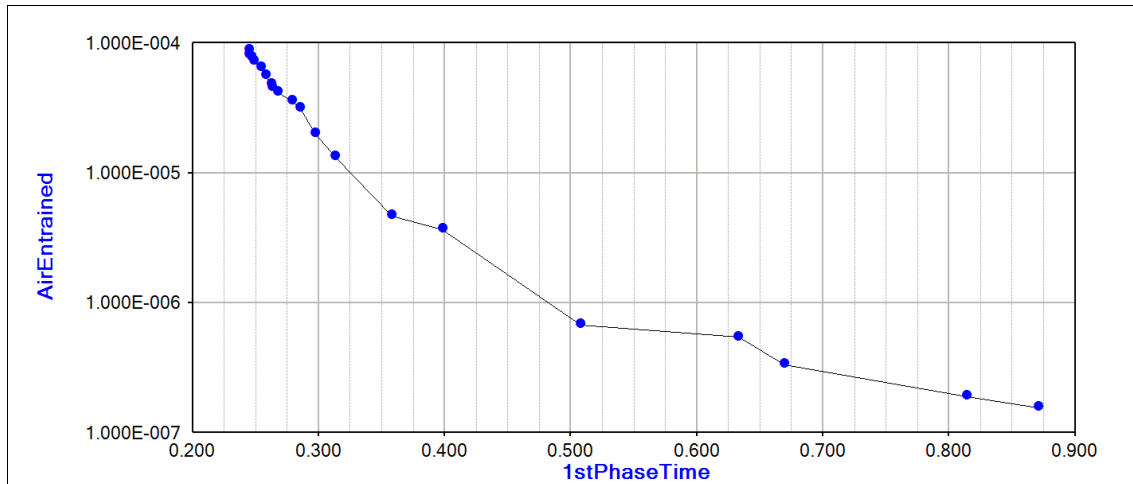


### Results

The first important aspect to clarify is that IOSO is not based on any specific algorithm (like gradients or genetic methods) but is a technology, that adapts itself to the surface response of an approximate model using the theory of artificial neural networks. The strategy then is not constant, but auto-adaptive.

The topology of the task, in this case, is quite peculiar and non-linear.

After some initial iterations to evaluate the surface response IOSO starts to produce the Pareto curve and to individuate some interesting optimal points. IOSO has been left working for a long time, even when very good solutions have been found. The Pareto curve at the end of the optimization task is the one showed in **figure 4**.

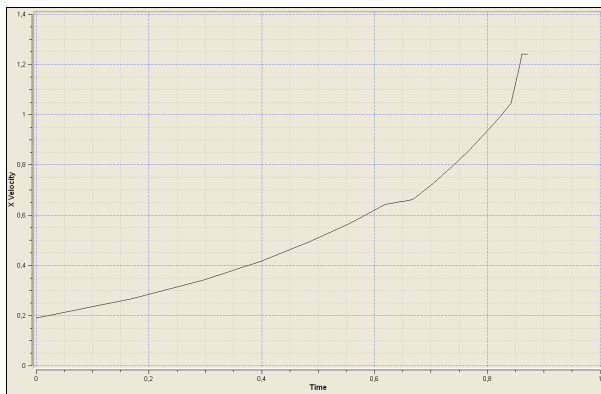


There are some interesting aspects to observe in that curve: first of all the curve found cover a wide range of values and with the two extreme quite robust. This last aspect is particularly important in an optimization process because commonly it is required that the solution found is not just something hard to reached but a reliable solution, that can be used even if there are some uncertainty on the parameters.

The second observation watching the curve is that, in any case, the maximum time to dedicate to the first phase stage is not more than 0.9 seconds. This value represent a process about the 30% faster than what is commonly used when, to prevent from surface breaking, the piston is moved slower (times are about 1.1 – 1.5 seconds) with consequent higher metal cooling and oxidations. To give another point of view: a higher cost for a lower quality.

Corresponding to the slowest process we have an associated air entrained practically null.

Every point of the Pareto curve is an optimal solution, and represents the best velocity profile to use for the piston for that particular compromise between time and air entrained.



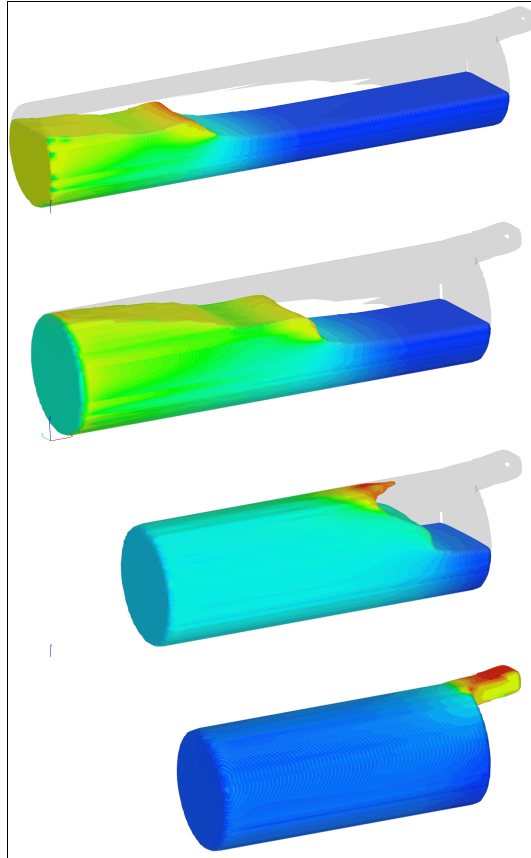
Nowadays foundries give a high importance to the fact of having a smooth surface and minimum wave breaking even with a slower process and so, for our test case, users may choose for the setup of their machine the rightmost solution point of Pareto curve.

The velocity profile connected with that point is showed in **figure 5** and, as previously said, it has an air entrained value very close to zero.

It is surprisingly observe that the velocity profile found by IOSO connected to this point, among all the infinite combinations of accelerations and decelerations, is very similar to what is actually used in the foundry world on Buhler machines based on

their experience: an initial slow and long acceleration, then a constant step, and a final steep acceleration. This velocity profile then not only follows the human logic, but it is also the best profile between all the similar ones.

Following mono-dimensional theories and the technical report referenced at the beginning of this document the optimal velocity profile is the one that catch up the starting wave moved by the piston without giving it the time to reflect or brake: watching an animation of the simulation (**figure 6**) the first impression is that this theory is almost caught.



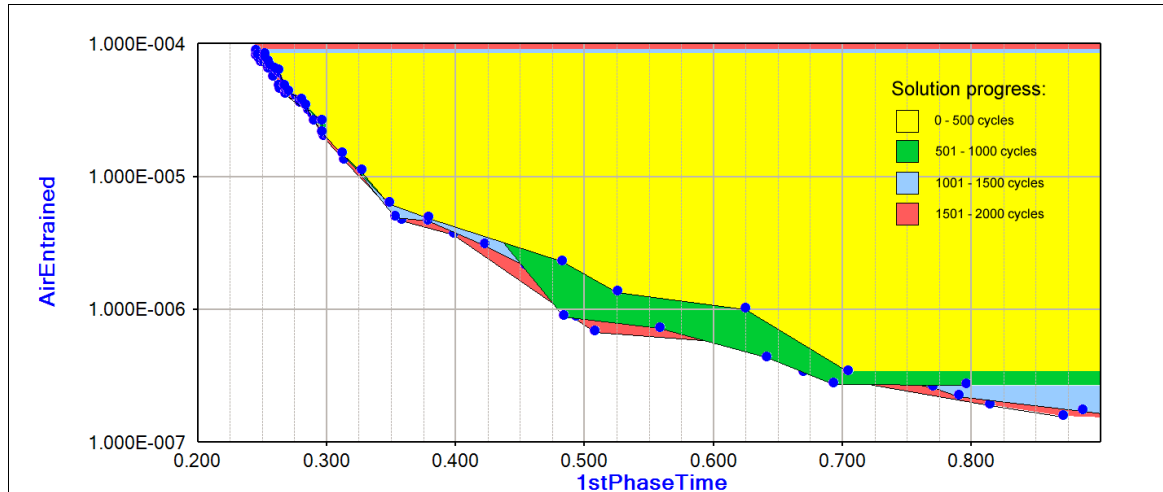
The piston controls the wave inside the domain by:

- increasing faster its steepness without breaking it, rising the metal height at the piston face;
- when the height is reaching the top part of the cylinder the acceleration is reduced smoothly, to delay as much as possible the increasing height of the wave and its touching with the top of the cylinder;
- when the wave touches the top of the cylinder and start to create a small upper running crest then the speed is increased fast, to don't let it falls.

The wave generated by the piston then is controlled by IOSO in order to reach high angles of steepness without having the time to brake or to touch the top of the geometry, and it is suddenly followed and caught up by the piston as soon as this equilibrium can not be maintained, in the last time-frames, preventing the formation of big air bubbles.

On more, the 3D simulation is able to find the breaking angle of the running wave with a much more accurate and realistic solution, going closer to the physical limits more than what can be predicted with simplified 1D or 2D theories.

To finish it can be important to make some considerations on the computational times of this optimization task. At this purpose we report the progression of Pareto curve found by IOSO during the computational cycles (**figure 7**).



IOSO has been left working for about 4 working days on a common home desktop machine, for a total of about 2000 calls. Comparing the curves we can observe that in reality many of the optimal solutions were found just after one day, and the convergence of Pareto solution has been reached near the end of the second day. In the following days, in fact, IOSO has been able just to make the solutions more robust, refining only few segments.

#### A further validation

To further investigate the optimal point found by IOSO related to the minimum air entrainment, a completely new task has been performed: a simple single objective optimization, minimizing the air and without any constraint on the process time.

After 1000 of cycles, the minimum point found has a slightly lower value of air entrained of the two-objective calculation (in a range of 2%), with a higher process time, this proves that the Pareto curve for such small values of air entrained (right side of Pareto plot) is quite flat, and that the optimal point found in the first task is real a good point that minimize one of the objectives.

#### Work extensions

To go deeper in the analysis of Pereto curve for small values of air entrained, a Robust Design Optimization task (RDO) should be performed, in order to identify what process time gives the most flexible and reliable solution for minimizing the air.

However, this analysis should be performed over a specific geometry (with casting ingates and feeding channels) and working condition. Applying the RDO to the general case showed in this report would not bring actually to results of higher interests.

The RDO should also be coupled with a parametric geometry generator, and a parametric STL generator software is one of the last work in progress of XC Engineering.

To conclude, we can affirm that since hpdc machines are becoming more evolute and programmable the choices of the user can not be simple, opening at the same time the possibility to have a perfect process and high quality products. In the example illustrated, coupling FLOW-3D with IOSO after just one working day it is possible to identify some setup for the machines so good to get simultaneously a shorter process and a higher quality for the final product.

Optimization process should be applied to specific design cases and with specific input data, due to the extreme dependency of the fluid flow from the metal level in the hot chamber and feeding channels shape.