Automating Injection Molding Simulation using Autonomous Optimization

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Autonomous optimization is coupled to injection molding simulation to help molders make more informed decisions with less manual labor. The concept is to automatically create and calculate hundreds or thousands of simulations within a predetermined design space of millions of possibilities to learn about the relationship between final part quality and the material, mold, process, and molding machine.

Instead of running ten simulations with an operator, the software is running hundreds or thousands of simulations on its own. Better decisions are then possible because there is significantly more information to base the decisions on. Obviously, making a decision based on five thousand simulated variations (variants) provides much less room for speculation than basing the same decision on only three or four simulations. With a larger sample size, there is a much clearer understanding of the relationship between the part/mold design and the process. This approach provides even more value to the molder because the software is completing a much larger portion of the work. It’s also completed well in advance of building a mold.

In a traditional simulation approach, an operator sets up a single simulation, clicks start, and then evaluates the results either while the simulation is running or after it’s complete. The evaluation requires time; look at individual results, think about them, decide if improvement is required, decide what inputs to change (probably as a group), make changes, click start, and repeat. The manually iterative procedure continues possibly several times a day for several days until the group is satisfied the result is as good as it will get with the time available. Each set up might take 15 minutes and each review might take another 15 to 30 minutes. Calculation times can vary from as little at 60 seconds or as long as an entire day. Manually operating the software for ten simulation designs can require a full workday of labor, maybe more.

The new, automatic approach is quite different. The software operator sets up the initial design which includes objectives, variables, and constraints. (This procedure can also be further simplified using preexisting templates.) The software automatically produces each future variant (simulated design) by changing the process and/or geometry in milliseconds, generates the mesh, queues it up for calculation, runs the simulation, and plots the results of the objectives. The results of all variants are plotted in a single chart so the operator can easily determine which of the variants produce the results which most closely meet their objectives (Figure 1).
The operator time is reduced from 7.5 hours to 0.75 hours (an improvement of 10x). The decisions of the operator are based on thousands of simulations instead of only a few.

This is something like a DoE (design of experiments), which is also possible. However, the main difference is that instead of simulating all of the variants, the software focusses on changes that produce results which more closely meet the objectives. The software knows what can and cannot be changed, how much it can be changed and what the objectives are to avoid creating unfeasible situations. It creates and runs multiple variants over several generations learning about which changes are most desirable. Several variants are calculated in parallel to speed the process. The faster the results are available, the faster the software learns what changes support our objectives. This is a completely different approach for solving problems or achieving new goals when compared to traditional simulation.

All molders don’t necessarily have the same goals, or constraints however. Some may want to find the lowest melt pressure to fit the largest part into the smallest machine while others may want to achieve the fastest cycle time. Some may have significant latitude on gate location or material selection while others may have none. Autonomous optimization may not be able to find the solution, but it can explore the complete realm of what is allowed to determine the best possible scenario. At least a molder can determine what the very best process is, how repeatable it will be, and what final part quality is attainable. Two very common problems molders encounter are;
1. Best gate location
2. Fastest cycle time

However, there are other objectives too, all involving part quality. Parts must meet dimensional, aesthetic, and mechanical requirements. Multiple objectives are used simultaneously now to ensure molders don’t end up with undesirable outcomes;

- Lowest pressure to fill a cavity but creates weak weld lines, or
- Least amount of trapped air but produces highest melt pressure

**Thermoplastic Injection Pressure and Weld Lines**

In a large thin-walled (2mm) unfilled thermoplastic part, the required injection pressure is forcing the part into a larger machine (or it runs in a smaller machine with an earlier transfer from fill to pack but then struggle to control the shrinkage). The part also exhibits excessive warpage even in the larger machine and requires a longer than desired cooling time.

The objective is to reduce the required injection pressure by moving the gates (the variable). It’s communicated to the software as: Minimize: *melt pressure* (@95% filled). On a more complex part design, there can be less flexibility on gate location.

Figure 8 shows in this case it’s a straight line to keep the gates connected to an existing rib. The blue gate can exist anywhere along its 90mm long line (rib) while the green gate can exist anywhere along its own 100mm long line (rib). Both can then move inwards or outwards in increments of 1.25 mm. This results in one gate with 51 possible locations while another with 61 possible locations creating a total design space of 3,111 possibilities.

![Figure 2 - Path shown for each gate to move along the part](image)

The constraints are basically everything else. Don’t change anything. The Autonomous Optimization finishes in 10 hours after running 112 variants. The results show the pressure from each design and how each outcome is better than the previous (Figure 9).
Autonomous Optimization allows for an efficient and easy way to analyze thousands of designs so a fast decision can be made. Figure 10 shows a scatter chart of the same data as seen in Figure 9. However, this scatter chart allows for a different visual representation of each design’s performance vs the desired objective of reducing filling pressure and highlights the best and worst designs.
The new gate locations which produce the lowest pressure compared to the original design (Figure 11a, b).

![Pressure comparison of worst design (left) vs best design (right)](image)

Figure 5 - Pressure comparison of worst design (left) vs best design (right)

The new design requires 22% less pressure than the original, allowing it to run in the smaller molding machine. But, there’s a problem...weld line results indicate a high degree of severity (100% actually). This is not acceptable and a compromise must be found. A new objective is created by adding an evaluation area around the weld line (Figure 12) location.

![Geometric evaluation areas are possible to resolve problems in specific locations](image)

Figure 6 - Geometric evaluation areas are possible to resolve problems in specific locations

The new design has two objectives; reduce weld line severity and reduce required injection pressure, but with the same variables; move gates. One can see from the initial results that these might be conflicting goals; closer gates make for a less visible weld line but farther gates require less injection pressure. The goal is to find the best compromise between the two, lowest melt
pressure and least visible weld line. The new objective is defined and the existing results from
the previous simulations (variants) are reorganized with both objectives in mind (Figure 13).

![Graph]

Figure 7- Best compromise found between required injection pressures and weld line strength

It is concluded now that the weld line strength is improved by 30% (reduced from 100% to below
70%) (Figure 14) at a cost of increased injection pressure of only 300psi which is still 17% lower
than the original. Weld lines in the original design are still visible having a weld line strength value
of about 70%. Further reduction in melt pressure is available via gate and runner diameter changes and would be the next step in this new approach.
A gate and runner optimization would be coupled to a viscosity curve study where the gate and runner diameters would be coupled to different filling speeds to determine the limits of the operating window. Saving further time at the molding machine trial.

**Thermoplastic Mold Cooling, Cycle Time, and Distortion**

Another common molding challenge is cycle time (specifically cooling time) vs. distortion. These goals are also conflicting. Shorter cooling time makes for a hotter part at mold open and likely leads to greater shrinkage outside of the mold (where there is no mold to hold it in shape), which results in a distorted part. A longer cooling time allows the part to cool more inside the mold, where it’s constrained (mostly) holding the part in place until it has higher strength. It shrinks less outside the mold and typically has less distortion. The objective is to find a way to reduce the part temperature at ejection in order to reduce the cooling time.

The variables are the 11 green cooling lines moving independently (Figure 15). The cooling lines are moving towards the hotspots in the mold in order to reduce the local mold temperature. Mold steel inserts in these locations were considered as another variable; Moldmax, H13 and S7. The objective is to Minimize: part temperature at ejection. Once the best cooling positions are found, the stress calculations for shrinkage and warpage are computed to evaluate the difference between best and initial scenarios.
There are 3 mold materials, 11 independent cooling lines with between 2 and 7 available positions, resulting in 3.3 million possibilities. Using Autonomous Optimization (goal-oriented objectives), the complete design space does need to be simulated. The software learns which variables result in reaching the objectives faster. In this case, only 176 calculated variants (8 generations of 22 designs each) were required to find the optimal solution (Figure 16).
Figure 11 - Designs involving MoldMax had better control over the mold temperature

Figure 17 shows the effect of different mold materials and waterline positions. MoldMax material yielded the best improvement. The hot spots in the mold reduced from 170F to 140F (Figure 18a, b) which resulted in a part temperature reduction at mold open from 300F to 265F (Figure 19a, b). Since the material can be ejected as soon as it reaches 285F, the results show this occurs at a cooling time of 37s compared to the previous time of 42s. The stress calculations are performed and show reduced distortion at a faster cycle (Figure 20). The amount of labor required to manually set up, and evaluate 176 variants is estimated at 50 hours while with Autonomous Optimization this is reduced to only 4 hrs.

Figure 12 a & b - Thermal gradient comparison in the mold highest (left) vs lowest (right)
The calculation time is extremely inexpensive compared to the cost of labor; the average hourly cost for software and hardware using a three year amortization schedule is only $5.00 and it works 24/7. The average hourly cost of a trained software operator is $50.00 (including salary, health insurance, retirement, unemployment, SS, etc.). So, it makes complete sense to focus on reducing the human labor factor since it’s 10 times greater. It also makes sense to focus on software development which computes more quickly. As more data is required for software to make decisions, more simulated variants are required to improve the accuracy of these decisions.
However, this approach is statistically proven to find better solutions. Most molders use live molding trials and DoE to make these “data-driven” decisions already. The cost of a live DoE trial (8 hr. sample including start-up and shutdown) ($1,000.00) compared to a virtual molding trial ($50.00) vary greatly and will help molders achieve levels of profitability not previously possible.