DEVELOPMENT AND APPLICATION OF CASTING DISTORTION & COMPENSATION TECHNOLOGY BASED ON AUTOMATIC ITERATION METHOD

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ABSTRACT
Casting warp or distortion is one of the main defects often encountered in the production of die-casting, it is also quite difficult to solve. The traditional methods have the problems of low efficiency, heavy workload and poor working environment. This paper introduced Cast-Designer's newly developed distortion compensation solver DCS (Distortion Compensation Solver), it can predict the casting distortion and warp in advance and find the casting products meet the tolerance requirements in the automatic iterative optimization technology. With such tools and technology, we can reduce the casting distortion effectively and meet the machining requirements directly.

INTRODUCTION
As an advanced manufacturing technology, die casting has the advantages of high dimensional accuracy, good mechanical properties and high production efficiency. It has strong technical and economic advantages in the production of automobile aluminium and aluminium-magnesium alloy parts.
However, for a variety of reasons, many die-cast aluminium components rarely consider the manufacturing factors in the initial design stage. The complicated structure, large wall thickness difference and high precision require great challenges in the development and production of die-casting. Among them, distortion and warp defect is one of the common and difficult to control problems of complex castings.
Casting distortion defects caused by many reasons, such as improper design of castings, castings unbalanced when eject out, and mould temperature imbalance. Distortion defects on the quality of castings mainly in the following aspects: 1) affecting the dimensional accuracy of castings; 2) affect the follow-up machining. 3) For the parts with too deep machining after casting, the hole defects (such as pores and shrinkage) inside the casting are exposed due to the remove of the dense layer on the surface of the casting, which affects the appearance and sealing performance of the casting (for the parts with sealing requirements).

The traditional method and challenges of casting distortion
Method 1: Process parameter adjustment: In actual production, the deformation of the castings is controlled within the technical requirements through mould design, spray cooling and adjustment of die-casting process parameters, etc., without changing the product structure. In this method, it is not always possible to obtain fully acceptable casting part whose deformation is within the specified value. And another problem of this method is processing stability.
Method 2: Increase casting allowance: For parts that need machining, it is to increase the casting allowance, to ensure that the castings can reach the required dimensional accuracy after machining. The consequences of this method are obvious. Increasing the machining allowance is equivalent to increasing the wall thickness of the castings. The internal defects such as porosity and shrinkage of the castings during die-casting are increased, and the probability of exposing the hole defects increases after the follow up machining. Therefore, increasing the machining allowance to solve the deformation of die-casting, it is not the right way.
Method 3: Artificial orthopedic method: For castings exceeding the deformation limit, orthopedic methods are usually used for dimension correction. The traditional artificial orthopedic method is using of wood

knives, wooden hammer, wooden stool and other tools beat the cast, forced to reduce the degree of deformation of the castings after the casting cooling down, removing the gating and runner, overflow and flash burr. This method is inefficient, heavy workload, noisy, poor results, and the product beating process may cause cracking, easy to springback in the actual production.

Method 4: Hot Orthotics: Orthodontics is performed before machining to reduce the casting deformation to ensure adequate machining allowances on all machined surfaces. The hot orthodontic work of the die-castings is to use the characteristics of high temperature (about 200 ℃) and good plasticity when just ejected from the die, and to force it to be pressed through the machine and the orthopedic mould to reduce the deformation. This method asks quite complex process and strong water cooling.

Accurate casting stress and deformation simulation (thermal stress and mechanical stress)

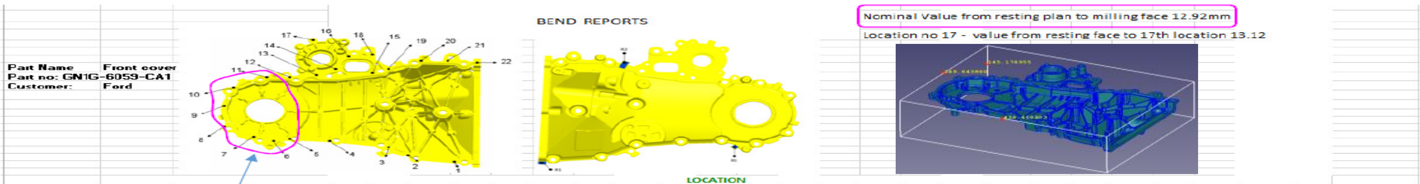
Before the casting distortion compensation calculation, we must get the accurate stress and strain result at first. During the casting process, liquid metal in the solidification and cooling process, the thermal stress brings big affection to the casting deformation. The thermal stress causes the tensile stress of the thicker wall and compression stress of the thin wall, because the cooling rate of the thick wall is a slow and thin wall is faster. The greater the difference between the wall thicknesses of the castings, the larger linear expand the rate of alloy, big elastic modulus of the alloy, then the thermal stress is also bigger. Specially, for directional solidification, due to the cooling rate was different in the casting different region, the thermal stress is also bigger than normal casting, and cause bigger casting deformation.

In the casting process, the stress usually includes thermal stress, mechanical stress and phase transformation stress. For aluminium or aluminium-magnesium alloy, thermal stress and mechanical stress are the main affection factors.

The stress module of Cast-Designer can analyze the thermal and mechanical stresses during casting process as well as the stress deformation. Thermal stress is reflected in the heat transfer and heat distribution during solidification and cooling, while mechanical stress is manifested as mould constraints and subsequent geometrical constraints during mould opening and closing. Cast-Designer's stress calculations can use a variety of material models such as rigid material, elastic material, elastic-plastic material, and more complex models of elasto-viscoplastic materials. In plastic material models, work hardening can also be considered.

Based on the finite element method technology, Cast-Designer can perform full-coupling analysis of thermal, flow and stress in the same mesh model to obtain more accurate results. Thanks to the thermal-flow-stress full couple technology, the influence of mold constraints and mold opening can be completely analyzed also.

Figure1 shows an automotive casting part, the part size is 438 X 350 X 145 mm, the average wall thickness was 3.3mm. As the left region of the product structure is simple, and the wall thickness is relatively thin and the right region is a complex structure, with thick walls. Such structure is very easy to cause part deformation after the solidification and cooling process. Therefore, in order to ensure that no pore exposed outside after machining, the machine allowance was set to 0.8mm on the big surface.



CASTING Sl.no	CASTING ID.	Bend Removal status	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Min	Max	DIFFERENCE
FD spring not working condition bend report (9 spring provision)																											
1		FD ejection Not working	12.90	12.92	12.91	12.86	12.87	12.94	13.10	13.34	13.40	13.34	12.90	12.98	13.05	13.00	13.10	13.06	13.20	12.98	12.96	12.90	12.90	12.90	12.86	13.40	0.54
2		FD ejection Not working	12.84	12.89	12.95	12.96	12.99	13.46	13.53	13.52	13.47	13.33	13.04	13.00	12.98	12.99	12.95	13.02	13.29	13.04	12.97	12.90	12.88	12.78	12.78	13.53	0.75
3		FD ejection Not working	12.91	13.02	13.07	13.06	13.09	13.17	13.28	13.46	13.68	13.62	13.48	13.24	13.07	13.06	13.05	13.09	13.44	13.18	13.08	12.99	12.97	12.89	12.89	13.68	0.79
4		FD ejection Not working	12.89	12.92	12.99	12.93	12.95	12.98	13.24	13.34	13.44	13.42	13.17	13.10	12.94	13.05	13.08	13.12	13.32	13.07	12.93	12.99	12.93	12.81	12.81	13.44	0.63
5		FD ejection Not working	12.88	12.92	12.98	12.90	12.78	12.96	13.21	13.20	13.19	13.16	12.93	12.81	12.86	12.90	12.87	12.85	13.09	13.00	12.92	12.92	12.87	12.81	12.78	13.21	0.43
6		FD ejection Not working	13.15	13.24	13.31	13.24	13.23	13.26	13.41	13.55	13.70	13.66	13.52	13.34	13.16	13.20	13.18	13.15	13.48	13.27	13.07	13.06	12.98	12.93	12.93	13.70	0.77
FD spring working condition bend report (9 spring provision)																											
1		FD ejection working	13.02	13.11	13.19	13.16	13.22	13.31	13.50	13.66	13.75	13.70	13.43	13.28	13.28	13.28	13.15	13.32	13.47	13.31	13.23	13.14	13.15	13.04	13.02	13.75	0.73
2		FD ejection working	12.86	12.92	12.94	12.91	12.93	12.98	13.13	13.23	13.30	13.26	13.13	12.97	12.85	12.85	12.86	13.02	13.21	13.01	12.95	12.96	12.90	12.79	12.79	13.30	0.51

Figure 1 Casting part and dimension after casting, the yellow cells are out of tolerance

As shown in Figure 1, select six different parts randomly in one batch, without any orthopedic circumstances, the casting flatness difference was 0.8mm, it could be considered as very large. In stress calculations, several physical parameters or factors must be considered, for example, the mould opening time was from 22 to 25 seconds, then eject out the casting part. After the part was ejected out from the mould, the average casting temperature was about 400 degrees, and put to water pool to cooling down. At 59.3 seconds, the castings temperature come to the room temperature (30 degrees). In Figure 2, for the effective stress contour with time was shown, it can clearly observe the stress release process.
Compared the flatness of actual testing result (No 2, 3 and 4 samples) and simulation result, it was matched very well, as shown in Fig.3. The red line is the flatness measurement result of the No. 2 test piece (respectively corresponding to 22 measurement points), the green line is the No. 3 test piece, the purple line is the No. 4 test piece, and the light blue line is the simulated result.

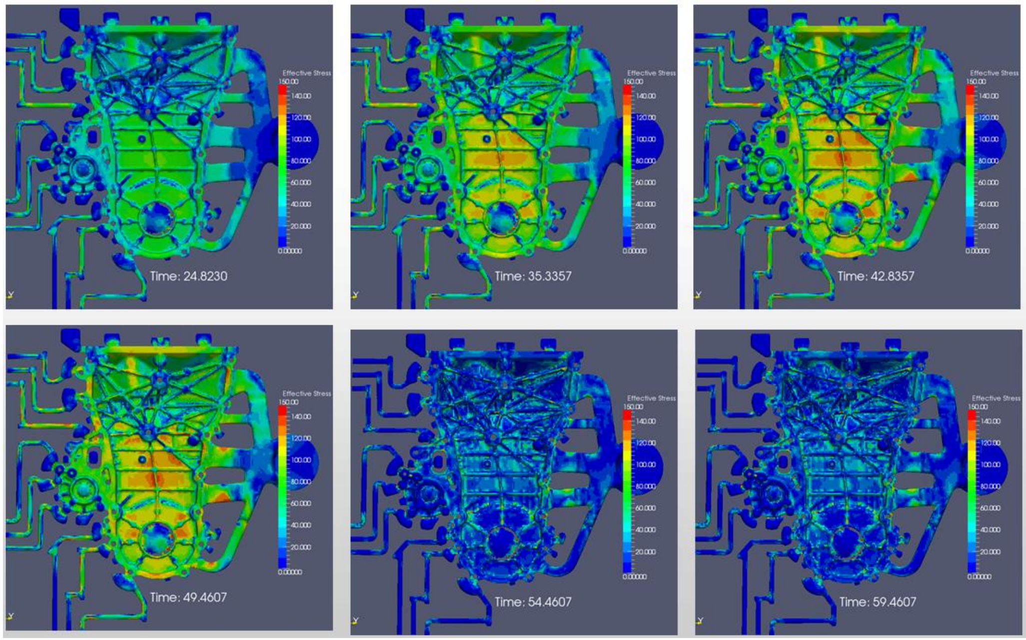


Figure 2 Effective stress contours vs. Time

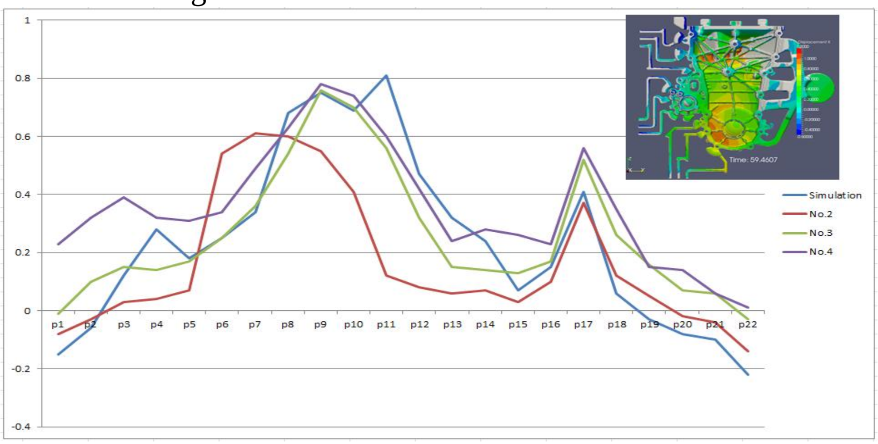


Figure 3 Part flatness analysis (simulation results vs. the actual measurement results)

Distortion Compensation Solver (DCS) principle and concept

In the mould design and manufacturing process, the cavity will consider the shrinkage of the casting solidification process to set a certain amount of liner shrinkage, but in most cases, the simplest overall enlargement and shrinkage is not suitable, the amount of post-processing will greatly increase. For example, in the cubic shape, but complex cylinder, casting is easy to produce in one face convex, but the other face outward deformation, not the overall shrinkage deformation. For these situations, Cast-Designer's distortion compensation feature radically changes the way "passive" predictive deformations are "actively" compensating for the deformation. As the deformation result, apply to the opposite direction to compensate for a certain percentage of the correct size, with several automatic iterative calculations, the deformation of the castings is close to the actual dimensional accuracy requirements. Such method can reduce the amount of post-processing. As shown in Figure 4

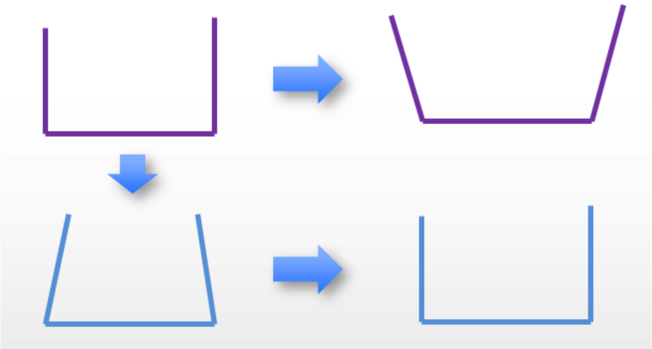


Figure 4 The first line: left: before casting right: after casting
The second line with compensation: left: before casting right: after casting

In order to correct the deformation and distortion of castings, the method of reverse deformation is usually considered in the process of mould design and manufacture. However, this method needs a lot of experience and with high risk for mould surface geometrically modification.
In view of above, Cast-Designer developed a new distortion compensation solver DCS (Distortion Compensation Solver). With DCS, users can simulate the deformation in the casting process, and gradually compensate for the deformation of the castings through automatic iteration simulation based on user-defined tolerance. The final result can satisfy the casting product requirement to close the tolerance.

The key technologies of deformation compensation

Accurate analysis of stress, strain and deformation-As mentioned earlier, accurate stress calculations and casting deformation prediction are the basis for the compensation technique. For high pressure die casting, both thermal stress and mechanical stress must be considered. And due to the complexity of the casting shape and the accuracy of the final product, the finite element method is the only acceptable analytical method today.In the analysis, the mould cycling and thermal balance also need consider, the cooling channel and heater also may bring directly affection to the casting part and mould, so the stress analysis model should be as accurate and detailed.

Automatic casting and mold geometry modification-Deformation compensation is usually calculated by iterative method. Based on the previous deformation and distortion value, the next compensation amount is adjusted according to the compensation coefficient so as to correct the mesh node coordinates. When revising the mesh, we also need to take several iterations to ensure the mesh quality and continuity of the mesh. At the same time, the contact interface nodes between the mould and casting also need to be modified. Due to the complex geometry of the mould, the meshing intersection and distortion must be taken into account when performing mesh correction.

Iterative Geometry Output and CAD Modification-The final casting geometry with compensation needs to be exported to the CAD system for modification. The best way to do this is to directly drive the modification of the CAD model, but the difficulty with this is obvious and each CAD system is different. In DCS, the user defines some important feature points and the program will automatically iterate and find the best shape to meet the tolerance requirements. Finally, the data of user-defined feature points can be reported and feed back to the 3D CAD system. The reported information includes the adjustment of each point and the final geometric deviation.

Compensation result

As shown in Figure 5, the white contour is the original casting part (the target dimension), the colored contour represents the deformed castings.
The flatness requirement of the product was 0.5mm. After the first iteration, the amount of deformation exceeded the tolerance and reached above 0.8mm. After four times of automatic iteration calculation,

finally, after the casting is cooled to room temperature, the flatness can be maintained between 0.05 and 0.15, and the product 100% meets the requirement of direct supply machining production.

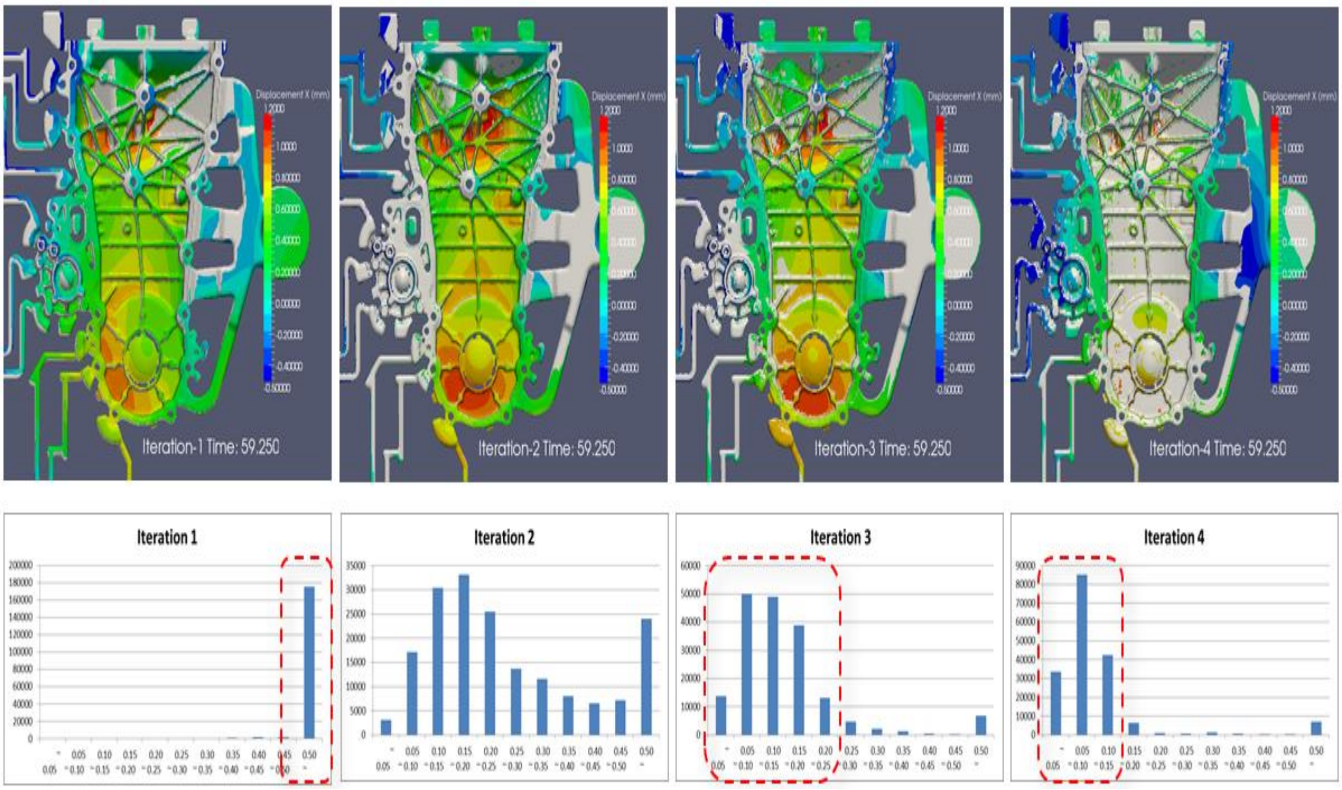


Figure 5 The compensation result after four iterations

CONCLUSION

Using computer simulation and automatic iterative compensation method can effectively solve the casting deformation and distortion problems. With this method, it is effective for the complex geometry casting, such as communication products, heat sinks, covers, automobile parts,etc.

For large orders, or the product has a large flat structure and flatness requirements of automotive parts such as chain cover, oil panel, electric car electrical cover and other castings, the application of deformation compensation technology can improve efficiency and reduce manpower cost.

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