ENGINSOFT

Structural Optimization of a Car-body High Speed Train - An Innovative Analysis and Design Methodology

One of the trends that are characterizing the market of the automotive components concerns the growing application of the cold chamber die-casting as casting production process. The reason is related to its cheapness, due to a high productive frequency and to the precision of the producible components. On the other hand, the particularly high velocities, that rule the process, affect the filling dynamics, characterizing it with turbulence effects the can lead to defects generation and degenerate into air entrapments or not completely filled parts.

In such a context, the product/process design assumes an extremely important role, since it's a very delicate phase in which the most effective solutions are evaluated in order to produce the equipment and to optimize the proper process parameters.

Development and Optimization of a productive process means to identify the variables that mainly impact on the product features, evaluating the effects with the support of advanced tools for process simulation.

This work describes as Tecnopress S.p.A., leader in die-casting components supply on a worldwide level, has applied the numerical optimization so to enhance the control on the production process of an automotive component, allowing to reachthe expected qualitative level without affecting the production cost.

Introduction

The actual market conditions force companies to react in a very short time, producing castings with high qualitative characteristics and competitive prices. In order to meet all requests, component suppliers need productive processes with high productive frequency, requiring a minimum effort of machining for finishing (net-shape parts), to be obtained for example with a high automatized die-casting process.An obstacle in such process can be detected in the difficult setting necessary to obtain a zero-defect casting; the high injection velocity of the metal and the complex shapes can generate the entrapment of the gases inside the die cavity and/or poor compaction of the solidification shrinkage. The process analysis under investigation is highly representative to prove the opportunities of the cold chamber die-casting for the production of automotive components, one of the most demanding industrial sectors in terms of performance. Furthermore it has been possible to demonstrate how the application of virtual optimization as decision making tool in the design phase can provide a great benefit, trying to estimate the advantages coming from the product quality maximization in relation to the customer's specific requirements.

Design of the die/equipment/casting system

The casting, as a result of the analyzed process, consists of a cover to obtain a pneumatic valve necessary to make a braking system operate. Heavy tracks (tracks, tractors, trailers, ets.) are commonly equipped with this kind of system.

This component is not affected by heavy mechanical stress, but has to guarantee a perfect tightness both on the working areas, where linings are often located, and on under pressure surfaces.

It's therefore a component of a safety system that has to guarantee a high operating reliability in accordance with the strictqualitative tests carried out in any production phase from casting to final assembly.

The consolidated approach to casting adopted by Tecnopress S.p.A. technical staff consists of a preliminary analysis of the component, so to define the most suitable configuration according to the features of the available company installations. Once the basic equipment conformation has been fixed (nr. of figures, parting lines, lateral slides, couplings and

dimples location, etc.), the adequate casting system is defined, that according to the experience should provide a good cavity filling.

Tecnopress S.p.A. has strongly integrated the casting simulation with MAGMA5 code in its standard design workflow for a long time now, so to rely on robust and reliable tools, able to guarantee its customers' with high quality products.

In this specific case, having no qualitative requirements provided by the customer, and considering the very short time for the first sampling production, it has been decided to start with a simple test, with a virtual analysis of the filling of the current design status.

The analysis of the results obtained by the first simulation has satisfied the design expectations on velocity and temperature distribution during filling but has highlighted some criticalities due to air entrapment in some casting areas (Figure 1). The indications provided by the virtual analysis has suggested that the dimples capacity should be increased and a further analysis has confirmed that this solution is considerably improving the situation (Figure 2).

It has been therefore decided to move to the die production and to proceed with the first sampling of the castings.

Preliminary SAMPLING of the castings

The production of the new equipment and the process parameters of the first sampling reflect the setup of the virtual simulation. Although the castings produced during the first sampling do not present particular defects on a visual inspection at a rough state, the pressure tightness tests (up to 13Bar in the air) after machining have produced a 30% of
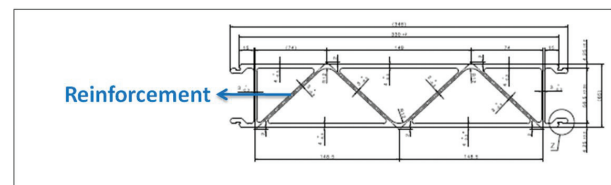

Fig. 1a - Fuselage Parametric part of high speed train: it has been completely development in ANSYS APDL. Fig. 1b: No -parametric part of high speed train: terminal tapered parts are fixed geometry
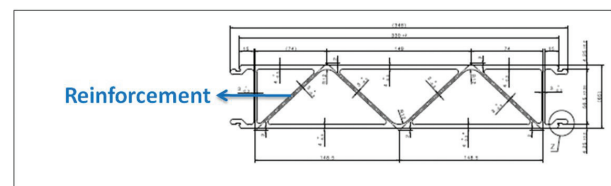

Fig.2 - Section profile of carbody

production scraps (Figure 3).

In agreement with the customer, the computerized industrial tomography carried out on the sample has allowed to identify the internal defects caused by air entrapment and/or by isolated volumetric shrinkage, directly in the sample casting and the following computerized elaboration allows its 3D view, as in Figure 3.

The analysis of the results achieved with the tomographies on some samples has allowed to identify two areas of the casting characterized by high concentration of porosity.

The critical closeness of such areas to some machined surfaces has

generated a high percentage of scraps in presence of porosity. The interpretation of the results achieved with the virtual analysis has therefore permitted the identification of the threshold over which porosity due to air entrapment can be detected as a consequence of the filling dynamics. The virtual analysis and the tomography have therefore allowed an in-depth understanding of the causes related to the non-quality at the end of the productive cycle but permitted to identify the problem solution.

No-Welded Area
$\sigma_{adm} = \sigma_{0,2} = 200$ MPa

Welded Area
$\sigma_{adm} = \sigma_{0,2}/S = 129$ MPa

$S = 1.55$ for thermally treated aluminum alloy

Fig.3 - Section of a carbody structure

OPTIMIZATION of the process

The approach followed by Tecnopress S.p.A.designers, looking for a solution to improve the process performance, has used the numerical optimization technology available in the MAGMAfrontier module. Once the virtual model is representative of the phenomenon under investigation and reliable in relation to the reference simulation, the optimizer allows a rational investigation on the quantitative effects caused by the variation of the parameters ruling the process and enabling to automatize the detection of the best configurations also for the systems characterized by a high level of complexity,as the die-casting one.

The real sampling activity has allowed to validate by comparison both the representativeness and reliability of the set virtual model. On such model several variables have been identified by technicians, according to their experience, that could be modified to rule the process.

Practically speaking, MAGMAfrontier is a tool requiring the definition of the objectives to be reached, as air entrapment minimization, shrinkage solidification reduction, as highlighted by the tomography analysis, in relation to the process parameters variability and to the casting system geometry. In particular, the geometric configuration of the casting system has been parameterized with respect to the thickness of the casting in-gates and to their location on the figure cavity (Figure 4), so to evaluate the effect of filling dynamics on the objectives to be achieved.

Furthermore it has been possible to limit the variability of the input (piston speed) and the output parameters (air breathers or pieces), that according to experience are not considered as possible, as for instance the maximum average speed at the casting ingate, which generates a quick wear of the matrix when overcoming a threshold value.

The optimization phase is based on the first series of configurations to be simulated (DOE, Design of Experiment), that have been selected using the

" Reduced Factorial" algorithm (such algorithm is based on two different levels of the "Full Factorial" algorithm, but only a part of the design is generated), together with "Sobol" which covers the vectorial space of the intermediate values in the most efficient way possible. The combination of these algorithms has allowedto fully cover the vectorial space of the input variables, thus guaranteeing their representativeness with respect to the population of the complete design. The following generations have been created by a genetic algorithm, called MOGA, that allows to determine the further design populations by combining the best design of the first DOE sequence using elitism and mutation criteria.

A set of 192 analyzed configurations constitutes the basis for the user to choose the best solution. The scatter chart shows in Figure 5 how each design is associated to a point in the Cartesian diagram, where the axis represent the objectives to be optimized (Figure 5).

The best configuration, identified by the optimizer, (Figure 6) has highlighted that the trend to entrap air in the critical zones of the casting is particular sensitive to conformation in the casting ingates. In particular, with respect to the first configuration considered, the first of the three casting ingates had to be adequately thickened, the second needed to be thickened and relocated, whereas the third only was to be relocated.

The optimizer therefore suggested a peculiar and not so intuitive configuration; in this sense it has been possible to understand how useful the tool can be, providing an important support to decision making, especially when highly complex problems have to be faced and several choices, not so easy to be compared, have to be evaluated. Matrixes have been coherently modified in agreement with the optimized configuration and the result of the sampling has been definitely satisfying, since it has allowed to reduce the production scrap from the initial 30% to a physiologic 2%. X-Ray controls on the sampled casting with the new industrialized equipment do not highlight porosity unconformity (Figure 7 and Figure 8).
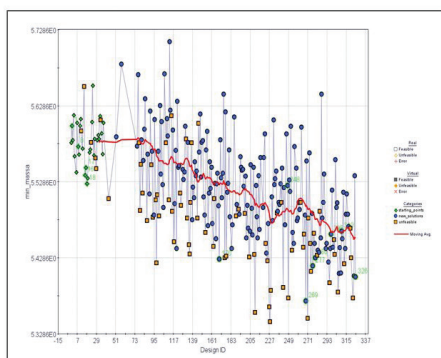

Fig.4a - History of weight convergence (green points: 1st optimization loop; blue points: 2nd optimization loop).
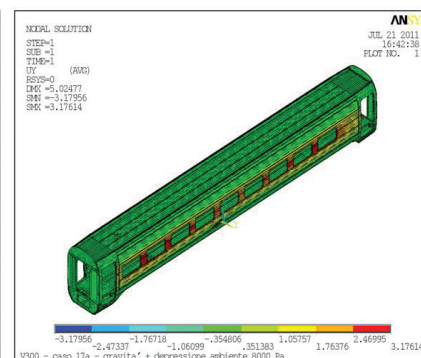

Fig.4b - displacements in y direction (mm)

Conclusions

This work presents a typical case of industrialization of the die-casting production process for an automotive component.

The problems identified during the development phase of the new equipment have allowed to prove the advantages offered by the virtual optimization, as support to the decision-making process in a context characterized by a high level of complexity.

In particular, the initial phase of the industrialization has been described; due to the very short time available, despite the

	DOE	Optimization Scheduler	Total Designs	Lower weight achieved
Step 1	Random : 52 designs	MOGA-II, 12 generations	624	5.535 tons
Step 2	Previous Pareto + Incremental Space filler : 47 designs	MOGA-II, 8 generations	376	5.414 tons
Step 3	Last Pareto	Mixed: MOGA-II + Simplex	112	5.377 tons

Table I - The table above summarize the optimization strategy adopted. The total number of design has been run in 20 days

Design ID	Mass [tons]	Δmass [Kg]	Uy [mm]	Uz[mm]	Frequency [Hz]
Original	5.927	-	> 3.5	> 4.5	< 11.0
378	5.377	-550	3.04	4.32	> 11.5
339	5.381	-546	3.09	4.85	> 11.5

Table II - comparison between the original solutions and the optimized solutions

<ID>	spess_e_512	spess_e_612	spess_e_712	spess_e_812
378	3.8	3	4.6	3.4
339	3.8	3.6	3.8	3.8

Table III - Thickness comparison of the side walls of fuselage (profile ref. 5-6-7-8)
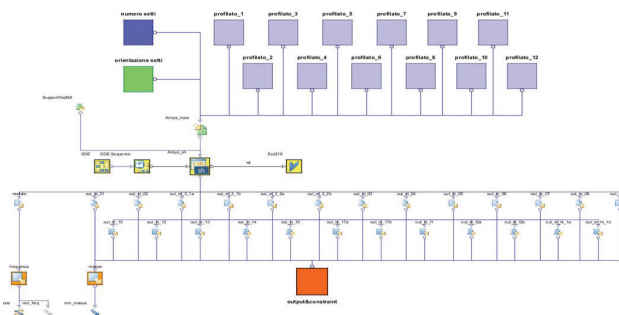
Fig.5 - The workflow of modeFRONTIER with all input and output variables, the final objective and constraints

Fig.6a - Parallel chart of the best designs

Fig.6b - The selected design (Design ID 339) with homogeneous thicknesses

advanced design techniques in use, the process was implemented with non-satisfactory qualitative performances, but the following virtual optimization phase has allowed a quick and cheap identification of a solving configuration.

The case under investigation can be considered as general valid demonstration of MAGMAfrontier usefulness to support the designer when looking for a robust and reliable sol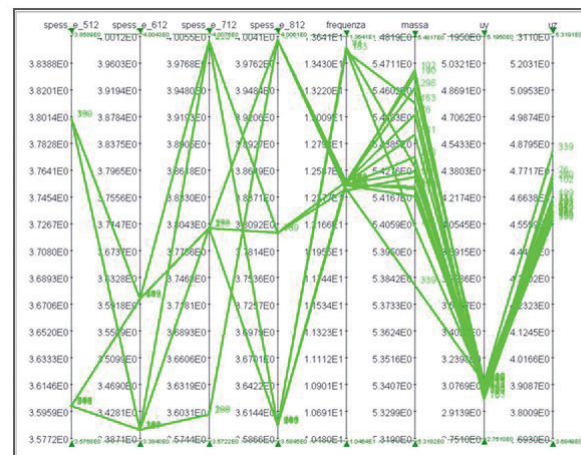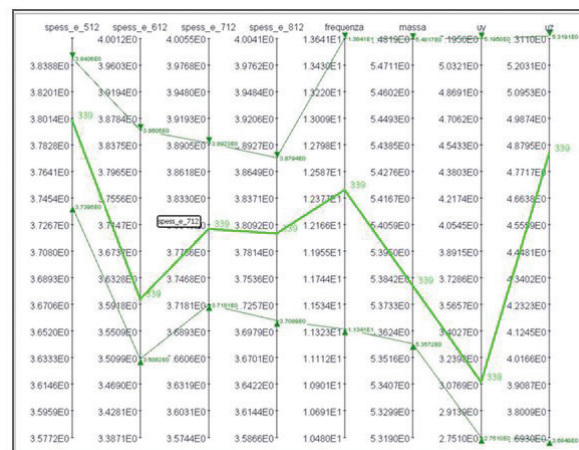ution to extend the die-casting application field to other sectors, requiring a high level of performance, thus keeping an eye on economic affordability.

Luca Bracchi, Cristian Bettinsoli, Tecnopress
Giampietro Scarpa, Nicola Gramegna, EnginSoft

EnginSoft is a premier consulting firm in the field of Simulation Based Engineering Science (SBES) with a global presence. It was founded in 1984, but its founder and initial employees had been working in SBES since the mid '70s. Throughout its long history it has been at the forefront of technological innovation and remains a catalyst for change in the way SBES and CAE technologies in general are applied to solve even the most complex industrial problems with a high degree of reliability.

Today, EnginSoft is comprised of groups of highly qualified engineers, with expertise in a variety of engineering simulation technologies including FEM Analysis and CFD, working in synergic companies across the globe. We are present in Italy, France, Germany, the UK, Turkey and the U.S.A. and have a close partnership with synergetic companies located in Greece, Spain, Israel, Portugal, Brazil, Japan and the U.S.A.

EnginSoft works across a broad range of industries that include the automotive, aerospace, defense, energy, civil engineering, consumer goods and biomechanics industries to help them get the most out of existing engineering simulation technologies.

www.enginsoft.com | info@enginsoft.com