Innovative control and real-time quality prediction for the casting production of aluminum alloy structural components

Thin-wall structural parts produced by high pressure die casting (HPDC) are designed and applied in the automotive production sector. The Audi strategy is the application of lightweight alloy components produced by HPDC in the structure of future car bodies. One of the key components of this strategy is the shock tower. The research of smart control strategies in order to improve the quality and production efficiency of these parts is a main objective of the technical center for HPDC of AUDI AG. An optimized cognitive method is therefore introduced and integrated in a single centralized control system. The shock tower use case is the selected demonstrator for testing and validating the cognitive control system. Based on an intelligent sensor network, communication with all devices, process data management and a quality prediction in terms of filling and solidification defects, a vast improvement of the casting production process is expected.
Thin-wall structural parts produced by high pressure die casting (HPDC) are designed and applied in the automotive production sector. The Audi strategy is the application of lightweight alloy components produced by HPDC in the structure of future car bodies. One of the key components of this strategy is the shock tower. The research of smart control strategies in order to improve the quality and production efficiency of these parts is a main objective of the technical center for HPDC of AUDI AG. An optimized cognitive method is therefore introduced and integrated in a single centralized control system. The shock tower use case is the selected demonstrator for testing and validating the cognitive control system. Based on an intelligent sensor network, communication with all devices, process data management and a quality prediction in terms of filling and solidification defects, a vast improvement of the casting production process is expected.

AUDI AG in Ingolstadt. The research activities are part of the project referred to as "MUSIC" (MUlti-layer control & cognitive System to drive metal and plastic production line for Injected Components) in the Seventh Framework Program of the European Union. The new approach in the field of information and communication technologies (ICT) will be explained in this paper with respect to the following topics:

- Intelligent sensor network for measuring the effect of the process setup and the stability of the thermo-mechanical behavior of the die
- Connection with all devices for acquiring data in a centralized database
- Configuration of the cognitive model for predicting the quality indexes relative to input in real-time
- Smart control application in production

INTELLIGENT SENSOR NETWORK

A mandatory requirement for the smart control strategy is the acquisition and storage of all data which influences the quality of the part, such as process parameters and sensor signals. In a first step, the existing die has to be modified to obtain an enhanced sensor network which is sensitive to casting defects. Process variables, which can be measured inside the cavity of the die by a sensor, are typically the temperature, the pressure and the time to melt contact. The sensors are positioned in the die based on simulation results. Possible positions for the integration of sensors in an HPDC die are limited to geometrical characteristics of the cast part and the resulting cavity of the die and interfering contours such as ejectors and cooling channels. It could thus happen that sensors cannot be placed in areas where quality defects will mainly appear. The challenge is to create a sensor network which can indicate all relevant quality defects within the existing restrictions of an existing die. The positions of the sensors within the cavity of the die are shown in Figure 1. Further information can be provided by sensors which are not positioned directly in the cavity of the die. Special stroke sensors were installed in order to monitor the movement of the squeezers. An opening of the die during the casting process was detected by four mold separation sensors which are placed in each corner of the die. In particular, the temperature control of the die has a great influence on the quality of the part and therefore it is monitored by a thermal-imaging camera system. The efficiency of the spraying process and the settings of the external thermoregulation devices can easily be monitored by using infrared imagery to measure the temperature in the areas of special interest on the fixed and moveable plates of the die before and after the spraying process.

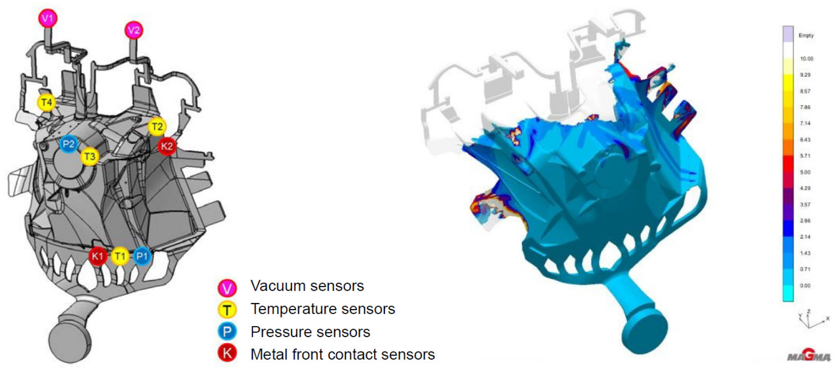

Fig.1 - Sensors in the cavity of the die and simulation to define the sensor locations

Connection with all devices

The main focus is on the sensor network in the die and the parameters of the shot curve, since these have the greatest influence on the quality of the part. In addition, the data concerning the connected peripheral devices has to be collected. For this reason the new OPC UA standard has been used to ensure a uniform approach in communication with the devices inside the HPDC cell. The connections with all devices can be seen in Figure 2.

The network with OPC UA communication includes the 2000t high pressure die casting machine, the thermoregulation, the sensor network and the thermal-imaging camera system.

Configuration of the cognitive model

For training the cognitive model, several quality characteristics have to be checked at different stages along the process chain. Starting with the melting process where the chemical composition analysis and the density index (i.e. gas content) of the liquid melt has to be checked. The cast part is analyzed by X-ray according to the specifications of ASTM E505 to detect shrinkage and porosity. Deformation of the part is measured by a device with digital gauges and stored in the database with respect to distortion before and after heat treatment. After heat treatment, the number and size of blisters on the surface of the entire part were documented. Finally, the tensile tests for the mechanical properties were performed for different areas of the part separated according to the distance from the ingate. The results of all quality checks were used to build a real meta-model of the process. Furthermore, data from the simulation was used to build a first virtual meta-model and to compare it and improve it with data from the real meta-model. For both meta-models a design of experiments was developed to configure different process parameters and sensitivity to sensor data and quality criteria . For the meta-model and the real casting process, thresholds to the permissible quality level of each quality defect have to be determined. It is possible to define a minimum level of quality for each area of interest based on the original specifications associated with an area of interest and a type of defect. Visualization of the meta-model is based on the correlation matrix and the parallel chart where the thresholds can show the effect on the process parameters to be used, or vice versa.

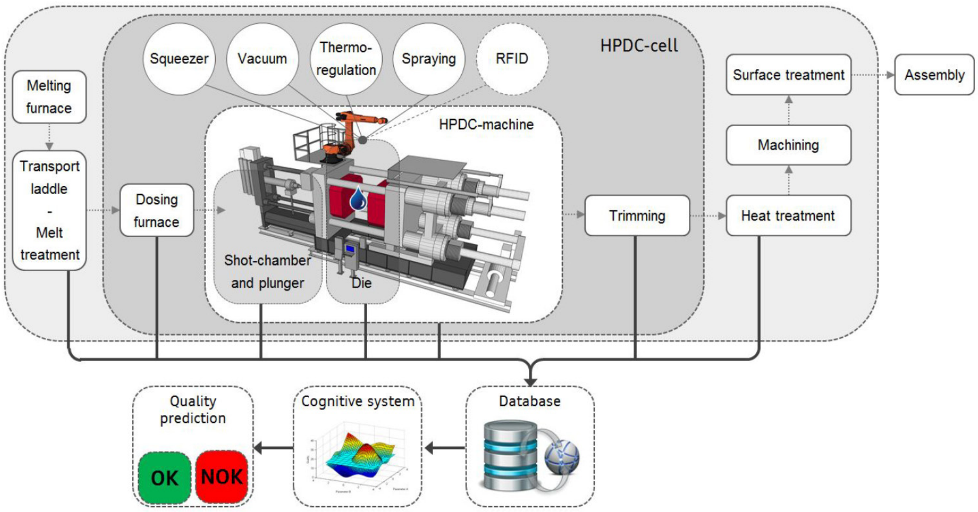

Fig.2 - Process chain with data connection

Since an HPDC die is a large investment, the die life influenced by different damage mechanisms and process parameters was also taken into account. The die life model will be implemented in the meta-model to prevent parameter settings which will lead to an excessive damage of the die in an early stage.

Traceability of parts is mandatory for assigning the measured levels of the quality characteristics to the produced part. For this reason, a data matrix code is attached to each part. For those parts, which were not used for heat treatment, the insertion of an RFID capsule during the casting process was tested.

Smart control application in production

The incremental learning family introduces a new way to optimize the accuracy of the quality forecast by searching for and selecting the best data mining algorithm among those available. Machine learning (ML) algorithms identify patterns in data and construct mathematical models using these patterns to achieve the best performance for the prediction and recalibration phases. The models need to be recalibrated in scenarios where new data become available, for example when a new quality inspection is performed during production, or when a new simulation process is completed. To maximize the accuracy of the predictions, it is crucial to develop an algorithm that is able to test the various available meta-models using the metric of cross-validation and to obtain the best one according to the imported data. New quality data is introduced using the 3D viewer web application in order to store them in the new extended table, selecting the location by clicking in the visualized geometry and applying the defect category and class from the available menu. The addition of new real-time observations allows the entire cognitive system to be quickly updated without the need to suspend production, thus without impacting the efficiency of the process. If some quality thresholds are set, the system responds during production by comparing the value of each prediction with the corresponding acceptability value for real-time predictions for rejects and good castings.

The “Smart Prod ACTIVE” tool (commercial name of the control & cognitive system) shows real-time quality results on PC, tablet or smartphone with information about the correlated causes generating the defects, about process stability and efficiency, and a statistic elaboration of the percentage of rejects and reference cost.

Conclusions

Since a reduction in the rejects rate will help to save money and energy during the production of castings, the use of a control and cognitive system will generate a benefit for the foundries. The preconditions for this are open interfaces and communication standards such as OPC UA. Especially with the increasing complexity of castings, a system with a reliable quality prediction and a well-founded database can help the worker to define and implement the right decisions.

Acknowledgments

This work was developed within the “MUSIC” Project (MUlti-layers control & cognitive System to drive metal and plastic production line for Injected Components), supported by European Union [FP7-2012-NMP-ICT-FoF] under grant agreement number n°314145. The authors would like to thank the MUSIC consortium (www.music.eucoord.com).

B. Kujat – AUDI AG
N. Gramegna – Enginsoft SpA
M. Benvenuti – DTG