HPDC foundry competitiveness based on smart Control and Cognitive system in Al-alloy products

Nicola Gramegna, Franco Bonollo

High Pressure Die Casting (HPDC) technology is facing new challenges in terms of quality requirements from the end-users, production rate achievable, process monitoring and control, in a complex worldwide scenario. A relevant contribution to HPDC competitiveness has been offered by the EU-FP7-funded MUSIC Project. It is probably the biggest research project ever carried out in the field of HPDC, with 16 partners and an effort of about 1000 person-months. MUSIC developed a totally new Control and Cognitive system, giving an integrated and multi-disciplinary answer to the most relevant issues for HPDC industry: "zero-defect" production, real time process control, understanding the role of process variables, process optimization and real time cost evaluation. The basics about this new Control and Cognitive system are presented in this paper.

KEYWORDS: INDUSTRIAL DIGITALIZATION - HPDC - INTELLIGENT SENSOR NETWORK - PROCESS MONITORING - REAL TIME CONTROL - QUALITY PREDICTION - COGNITIVE SYSTEMS - ZERO DEFECTS

INTRODUCTION: FACTORY OF FUTURE AND INDUSTRY 4.0

The so called Industry 4.0 is the industrial revolution based on Cyber-Physical-Systems (CPS). In the context of Factory of Future (FoF), the smart manufacturing, or Factory 4.0, is part of Internet of Thinks (IoT), of Services and People. The well-known digital transformation of the industrial value chain is relevant for smart grids in the field of energy supply, advanced materials, sustainable mobility strategies (smart mobility, smart logistics) and smart health in the realm of healthcare. The new and radically changed processes in manufacturing companies are applied for new technologies such as Sensors, 3D printing and next-generation robots or globalization of supply chain. The digital innovation is not an exclusivity of new and advanced technology and production processes. The traditional production processes and plants are evolving following this digitalization combining the long experience and the new fast methods to improve the production efficiency and to accelerate the fine-tuning and real-time adjustment of the process parameters oriented to the zero defect quality.

Evolution instead of Revolution. The FP7- MUSIC project (funded in the frame of the Call FoF-ICT-2011.7.1 Smart Factories: Energy-aware, agile manufacturing and Customization) is giving a new age to the traditional multi-stages production processes such as High Pressure Die Casting (HPDC) and Plastic Injection Moulding (PIM). The use of Sensors, the totally integrated systems, as well as the data mining and cognitive model are the key ingredient of the MUSIC project to be a reference in the Industry 4.0 context. Having this general context clear in mind, it becomes evident that all project objectives are focused on trans-sectorial production technologies, larger European market, capability of manufacturing site to be flexible, fast and reactive, manufacturing customization and environmental friendliness, management of manufacturing information, ICT application to improve the manufacturing process, new metrology methods and international standardization.

Nicola Gramegna
Enginsoft SpA, Padova, Italy

Franco Bonollo
University of Padova - DTG, Vicenza, Italy

THE FOUNDRY MARKET AND HPDC MULTI-DISCIPLINARY PROCESS

European Aluminium foundries are a group of about 2600 companies, which produced 3 million of tons of castings in 2011. Key players are Germany and Italy, with 60% of total production from Europe (0,931 and 0,844 Mio tons for Germany and Italy corresponding to a turnover of 5.092,00 and 4.051,00 Mio of euro) and an average number of employees of 15 in Italy and 96

in Germany (source CAEF). The 50-60% of Al alloy castings are produced by HPDC process. Categories of diecast products as thin wall and safety castings (represented in MUSIC project by a shock tower manufactured by AUDI) and Housing and Covers (represented in the MUSIC project by a gearbox manufactured by RDS) are the 75% of the total HPDC production (Fig. 1).

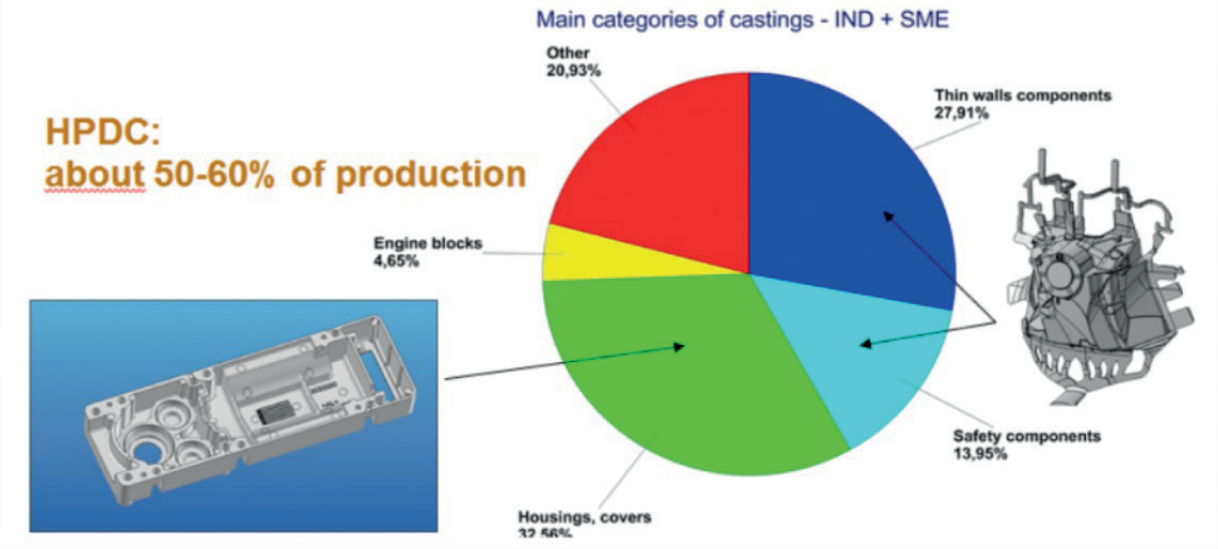

Fig. 1 - Main categories of high pressure die casting products

High Pressure Die Casting (HPDC) of light alloys is one of the most representative large-scale production-line in manufacturing fields, which are strategic for the EU-industry largely dominated by SMEs. Due to the high number of process variables involved and to the non-synchronization of all process parameters in a unique and integrated process control unit, HPDC is one of the most "defect-generating" and "energy-consumption" process in EU industry showing less flexibility to any changes in products and in process evolution [1]. Sustainability issue imposes that machines/systems are able to efficiently and ecologically support the production with higher quality, faster delivery times, and shorter times between successive generations of products. This is the scenario of the MUSIC project, strongly aimed at leading EU-HPDC factories to cost-based competitive advantage through the necessary transition to a demand driven industry with lower waste generation, efficiency, robustness and minimum energy consumption.

The development and integration of a completely new ICT platform, based on innovative Control and Cognitive system linked to real time monitoring, allows an active control of quality, avoiding the presence of defects or over-cost by directly acting on the process machine variables optimisation or equipment boundary conditions. The Intelligent Manufacturing Approach (IMA) works at machine-mould project level to optimise the production line starting from the management of manufacturing information. An Intelligent Sensor Network (ISN) monitors the real-time production acquiring the multi-layers data from different devices and an extended meta-model correlates the input and sensors data with the quality indexes, energy consumption cost function. Data homogenization, centralization and synchronization are the key aspects of control system to collect information in a structured, modular and flexible database. Process simulation, data management and meta-model are key factors to generate an innovative Cognitive system to improve the manufacturing efficiency.

CHALLENGES AND PROPOSED SOLUTIONS

Introducing intelligent manufacturing systems in HPDC, made available by autonomous and self-adaptive devices, changes totally the actual organization and potential of this process. According to the experience of MUSIC Partners, which are well established players in the HPDC manufacturing scenario, six main challenges have to be faced for the progress in this field.

These challenges are directly addressed by MUSIC project multi-level objectives and answered by several specific outcomes, associated to the main breakthroughs identified as follows:

Challenge #	Represents the breakthrough
①: leading HPDC/PIM to "zero-defect environment	Quality improved and defects minimised
②: introducing real-time tools for process control	Process data acquired by real-time tools
③: monitoring and correlating all the main process variables	Extent of knowledge of Process data vs. Quality as well as vs. Maintenance
④: making the process set up and cost optimisation a knowledge-based issue	Extension of average die life, Cost reduction in HPDC/PIM production cell, Process efficiency (energy & material) improved
⑤: involving to multi-disciplinary R&D activities	Control & Cognitive System
⑥: impacting on EU HPDC/PIM companies, by dissemination and standardization activities	International standardization

The innovation aspects introduced by MUSIC project results are referred to process optimization, centralized control of multi-stages production efficiency as detailed in the following list:

- A new Control and Cognitive system (the "smart Prod ACTIVE" tool), from design chain simulation and process optimization to real-time quality and cost models, is ready for the market,
- The High-performance production is supported by introducing advanced Sensors Network and Centralized data management to control all stages and tools in the production line,
- The process data, recorded in a proper database, are managed and elaborated in real time to predict Quality and Cost of single product through advanced and trained process meta-models,
- The Machine operator, the Production manager or Plant director are supported by smart web-based GUI to remotely visualize and navigate the real-time or historical process data.

PROCESS PARAMETERS AND COGNITIVE PREDICTIVE QUALITY MODEL

The "smart Prod ACTIVE" tool (Fig. 2) predicts the quality, energy and cost of the injection process in real-time, covering the 100% of products, and suggests the appropriate re-actions to adjust the process set-up and/or
mechanism. It works in combination with the real time monitoring system (or Intelligent Sensor Network) to elaborate instantaneously the production data set with respect to quality/energy/cost prognosis. The client-server
mechanism works in combination with the real time monitoring system (or Intelligent Sensor Network) to
elaborate instantaneously the production data set with respect to quality/energy/cost prognosis. The client-server

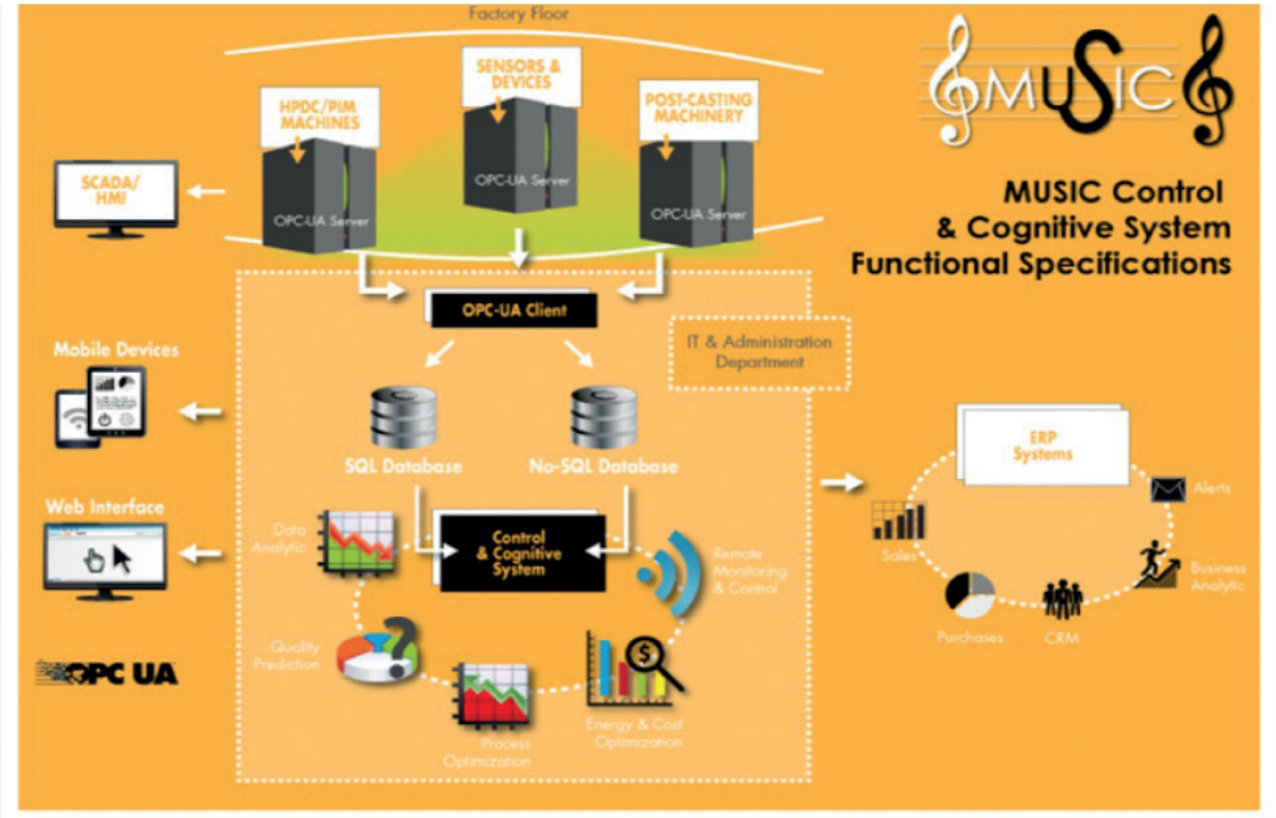

Fig. 2 - Introducing the "smart Prod ACTIVE" tool with the client-server structure in the factory floor

Connections, based on OPC_UA protocol that is accepted as Interface for Industry 4.0, are collecting all process data coming from all existing devices [2-3] and active sensors in a centralized database.

A fundamental innovative characteristic of "smart Prod ACTIVE" tool is the Cognitive predictive quality model integrating multi-resolution and multi-variate process data, monitored and gathered by an articulated network of sensors by means of the collection of distributed control system, advanced models linking process variables to specific defect generation mechanisms [2], new optimization tools and remote management of production by self-adaptive equipment. The real-time visualization of elaborated data, including safety messages and statistic production diagrams, will be appropriately customized for multiple users' interfaces as machine operator, production manager and plant director. The standardization Quality classification and investigation methods [4-5], as well as the traceability, are fundamental to train the Cognitive model guiding the minimization of relevant indexes affecting the scrap rate. The final tool is a smart web application to visualize, share and communicate the significant

data and to support the decision making with proper reactions in real-time (retrofit) based on the captured signals from the process and intelligent elaboration of data by the quality model.

THE EXPECTED IMPACTS

The MUSIC project introduces new ICT technologies at manufacturing plant with significant potential impacts: (i) strengthened global position of EU manufacturing industry; (ii) larger EU market for advanced technologies such as electronic devices, control systems, new assistive automation and robots; (iii) intelligent management of manufacturing information for customization and environmental friendliness. Expected benefits are:

- 40% reduction in scrap rate for the involved HPDC foundry,
- -3% in no-quality costs for the involved automotive company,
- up to 40% decrease in the cost of quality control, to be applied only to specifically individuated products,
- 5-10% reduction in energy consumption, due to scrap reduction and increased production efficiency,
- better knowledge and control of the process, resulting in time to market reduction and minimization of trial & error approaches.

CONCLUSIONS AND FUTURE DEVELOPMENTS

Due to the high number of process variables involved and to the non synchronization of all process parameters in a unique and integrated process control unit, HPDC is one of the most "defect-generating" and "energy consumption" processes. Sustainability imposes that machines/systems are able to efficiently and ecologically support production with higher quality, faster delivery times, and shorter times between successive generations of products. The new "smart Prod ACTIVE" tool is a flexible and totally integrated system able to predict the real-time quality and the cost. Its extension of application to further multi-stages and multi-disciplinary production lines (e.g. sheet metal forming, forging, rolling, thermoforming, machining, welding, trimming, or the innovative additive manufacturing) is planned to exploit the same methodology in different industrial contexts.

ACKNOWLEDGMENTS

This work was developed inside 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, grant agreement n° 314145). The authors would like to thank all Partners of MUSIC consortium (www.music.eucoord.com).

REFERENCES

[1] F. BONOLLO, N. GRAMEGNA and G. TIMELLI, Journal of Metals, 67 (5) (2015), p 901.
[2] F. BONOLLO and N. GRAMEGNA, The MUSIC guide to key-parameters in High Pressure Die casting. Assomet, Milano (2014)
[3] N. GRAMEGNA, Proc. 3rd High Tech Die Casting, Vicenza (2006), AIM, Milano (2006), paper n. 34
[4] E. GARIBOLDI, F. BONOLLO and P. PARONA, Handbook of defects in HPDC. AIM, Milano (2010).
[5] N. GRAMEGNA, I. LOIZAGA, S. BERROCAL, F. BONOLLO, G. TIMELLI, S. FERRARO, IFIP Advances in Information and Communication Technology, 397, 1 (2013), p 502.