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A Smart Maintenance tool for a safe Electric Arc Furnace

Luca Fumagalli*, Marco Macchi*, Cristian Colace, Maurizio Rondi**, Alessandro Alfieri***

**Department of Management, Economics and Industrial Engineering, Politecnico di Milano, P.za Leonardo da Vinci 32, 20133 Milano, Italy - Contact author's email: luca1.fumagalli@polimi.it*

***Tenaris Dalmine S.p.A., Piazza caduti 6 luglio 1944 n.1 - 24044 Dalmine (BG), Italy*

Abstract: The production process in steel making involves plenty of variables to know the actual status in plant operations and the deviations from optimal and safe operating conditions. The deviations depend on diverse uncertainties due to the material variability and, more in general, the complexity of modeling the physical and chemical transformations occurring in the production assets. The transformations are partially observable by means of measurable parameters. The "man in the loop" is then essential to cope with the tasks of monitoring, controlling and diagnosing the asset health status. Today, these tasks can be aided by the plant automation as a lever to support supervision and decision by the operators. The project reported by this paper was developed in this context, leading to enhance the decision-making capabilities. In particular, a condition monitoring tool was deployed by seeking the opportunities provided by plant automation enhanced according to Industry 4.0 paradigm. The tool is now running on an Electric Arc Furnace of the steel making plant of Tenaris Dalmine, in Italy. The project used the experience and knowledge gained by Tenaris Dalmine process and maintenance operators as foundation for initiating the conceptualization of a novel and approach. Thus, the tool – resulting from engineering and implementation of the concept – is integrating plant automation with intelligent data analytics, as a result of close collaboration between Tenaris Dalmine and the Manufacturing group of the Department of Management, Economics and Industrial Engineering of Politecnico di Milano. The tool enables to detect incipient failures through monitoring of the furnace panels and of the hearth/bottom of the furnace; thus, it allows to enhance the operations by avoiding downtimes that may lead to risky consequences on people safety. The tool has to be considered an example of smart maintenance and its implementation reflects a path towards building cyber-physical systems in production.

Keywords: Condition Based Maintenance, Production system safety, Fault tree analysis, Data analytics.

1. INTRODUCTION

The deployment of a condition monitoring tool on an Electric Arc Furnace (EAF) of the steel making plant of Tenaris Dalmine, located in Dalmine (Italy), is presented by this paper. In steel making plants, the furnace is the most relevant asset in terms of safety issues. Due to the characteristics of the furnace – running continuously at high temperatures and in harsh environmental conditions –, many components cannot be visually inspected, thus an intelligent maintenance tool, featuring real-time monitoring capabilities, represents a solution to increase visibility on, and keep under control, the asset health status. The implementation path of the intelligent maintenance tool and the results achieved by its use in the plant are herein presented.

Safety is claimed as an important issue in process design and in the operations in the chemical process industry (Zhao et al., 2009), and the risks for workers must be carefully considered (Barreto et al., 1997). To this end, maintenance is charged with a high level of responsibility and organizational involvement, encompassing also issues related to the: i) asset lifecycle optimization, ii) safety management and iii) environmental management.

Today, these organizational requirements can be supported by a mature state of the art favouring the implementation of CBM (Condition Based Maintenance) programs as well as by the novel capabilities promised by the transformation brought about by the Industry 4.0 paradigm. Indeed, "two of the characteristic features of Industry 4.0 are computerization by utilising cyber-physical systems and intelligent factories (…). Maintenance is one of the application areas, referred to as Maintenance 4.0" (Kans et al., 2015). In other scientific context, Maintenance 4.0 is related to what is defined as Smart Maintenance (Lee et al., 2006). Call this evolution as you want, the new Maintenance 4.0 solutions are worth to be considered as a lever to foster the achievement of relevant results in asset and maintenance management (Deloux et al., 2008; Huynh et al., 2012 and Djurdjanovic et al., 2003).

Various works have been presented, and scientific literature is plenty of innovative approaches, implicitly or explicitly referred to as Maintenance 4.0, Smart Manufacturing, or with the most traditional idea of e-Maintenance (Lee et al., 2006 and Muller et al., 2008, Guillén et al., 2016). Many innovative solutions about prognostics (e.g. Abichou et al., 2012), diagnostics (e.g. Fumagalli et al., 2011) and mixed reality tools (e.g. Espindola et al., 2011 and Espindola et al.,

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2013) are indeed available, and such smart maintenance systems are expected to progressively enter in the industry in various sectors.

As stated by Warren Bennis, "the factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment" (Fisher 1991). Being quite far away from this long-term vision, the focus nowadays should be on the practical application of a few but effective technological solutions to pave the way towards the next generation of manufacturing systems. In other words, the ambitious aim of the factory of the future still stands. It can be also agreed in steel making with a special emphasis on the safe operations of the production assets: keeping the human as far as possible from inappropriate interventions on the machines/plants is an imperative, eventually leading to keep the optimal asset use and to avoid introducing risks for the operators.

To move towards this end, a Smart Maintenance tool should provide as much as possible a complete visibility of the asset health status, thus avoiding a need of maintenance operators' intervention in the nearby of the asset. This research aims at presenting a proof of usefulness of such a type of tool, by discussing a practical implementation in the steel making industry as well as by providing evidences of how the data coming from the plant floor level can be transformed into relevant information, namely relevant indicators, elaborated and displayed at an upper level for managing decisions. The paper grounds on some first information provided by Barreto et al., 1997; Colace et al., 2013 and Colace et al., 2015.

The tool has been developed in an industrial environment, at Tenaris Dalmine plant, with the purpose of its practical use in the day-by-day operations. The measurable parameters are the relevant ones for applying a condition-based operation of the furnace: if operating conditions are approaching risky situations, they can be identified thanks to the tool, revealing the asset health status, eventually leading to the subsequent operational decisions by the operator. More specifically, the tool aims at monitoring the parameters of the furnace on the cooling panels and on the refractory bottom/hearth. To this regard, in this paper we will refer to the tool also as a Smart Water Monitoring according to its primary functionality. This communicates the value of the functionality: the tool helps managing the information gathered through the analysis of data resulting from the monitoring of the cooling water of the EAF; therefore, building on such a monitoring, information extraction leads to a "smart water" that conveys the relevant indicators for the asset health status. This type of analysis enables to make evident how the concept of digital twin, that is typical of Cyber-Physical Systems (CPS), is actually being implemented in the case. More specifically, it is remarkable a reduction of distance between the physical transformation – happening in the cooling water – and even physical-chemical transformation – occurring in the furnace and influent for the physical transformation of the water – and the cyber level implementing the analytics: it could be asserted that the monitored water, used as the conveying entity, is acting as a digital twin indirectly linking to the physical and chemical transformation affecting the asset degradation (i.e. cooling panels of the furnace).

From a methodological perspective, we can say that the Smart Water Monitoring leads to envision information about the furnace available in the tool. It is the result of a first step towards building the CPS perspective: it can be asserted that the actual implementation reflects, at least, part of the implementation path required for CPS in manufacturing. Using, as a reference model, the 5C architecture for implementation envisioned by (Lee et al., 2015), we may assert that the implementation path has been initiated through the first two levels, i.e. the Smart Connection level and the Data-to-Information Conversion level. This paper especially concentrates on the Data-to-Information Conversion level, presenting the novel approach resulting in it.

The approach used to develop and implement the condition monitoring tool is summarized in three main steps:

i) Fault tree analysis, to understand how the system under study can fail and the related critical scenarios to identify the key measurable parameters (i.e. key variables) to monitor and map the asset behaviour;
ii) Engineering and deployment of the State Detection and Health Assessment tools (part of the overall Smart Maintenance tool);
iii) Implementation and integration of the tools in the existing ICT architecture of the plant.

The steps enabled to create the analytics now running the Smart Water Monitoring. They are discussed through the following structure of the paper. Section 2 introduces the furnace and its key elements. Section 3 summarizes the use of fault tree analysis, to identify the deviations in the process parameters and, thus, to select the signals needed in order to represent the asset behaviour in its degradation. The signals are then the relevant input of the tool. Section 4 presents the development of the tools for state detection and for health assessment. Section 5 illustrates the implementation of the Smart Maintenance tool in ICT architecture. Section 6, through three real cases, describes the rich output information for the process supervisor and for the maintenance engineer provided by the tools. Eventually, Section 7 provides conclusions, envisioning some future steps towards the implementation of CPS in EAFs.

2. FURNACE DESCRIPTION

The EAF is constituted by a lower sheet metal keel (lower-part) coated with refractory bricks, which serves to contain the liquid steel, and is cooled by a cage, with a structural function, that supports panels cooled by a water circuit (Ferro et al., 2007). In the heating process, the panels cooled by a water circuit could be stressed out, and therefore fail with a leak of water in the furnace, which is finally leading to risky situation. The panels are particularly relevant for the present research.

In Tenaris Dalmine plant, there are two electric furnaces with the following characteristics: capacity 105 t, diameter 6.1 m, weight of the structure (considering also refractory bricks) 230 t. The characteristics of each furnace allow to obtain 98 t